Biased learning of phonological alternations

by

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Abstract of the Dissertation

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What is the initial state of the grammar when children begin to figure out patterns of phonological alternations? This thesis documents the developmental stages of children acquiring Korean verb and noun paradigms, and provides a unified account using the initial Output-Output correspondence (OO-CORR) bias. It is claimed that OO-CORR constraints are undominated in the initial state but the empirical evidence for this claim is primarily anecdotal. I provide experimental support for the claim.

In the acquisition literature, children's innovative forms are normally attributed to imperfect or incomplete mastery of the adult grammar. The evidence presented in this thesis suggests that children in some intermediate stages are able to produce adult forms when the syntactic context demands it, but otherwise they avoid doing so if the forms involve phonological alternations.

The specific way that children satisfy OO-CORR constraints is to inflect forms so that the output is faithful to one specific slot of the paradigm, the base form. I show that children select the base form by considering both phonological informativeness and the availability of the surface forms, and try to achieve paradigm uniformity on the basis of the base form in their production.

Assuming an initial bias to output-output correspondence constraints, I model the attested learning trajectories. The observed intermediate stages are correctly predicted, showing that the learning of certain alternations is facilitated when they share structural changes with other alternations. Artificial grammar learning experiments confirm that featural overlap of alternations facilitates the learning of the patterns. I propose a learning model that incorporates the attested learning biases.

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I am indebted to Adam Albright for all aspects of my research, career, as well as general life matters. As a young and stupid first-year student, I walked into Adam's office, was encouraged by his big smile, and told him that I would like to work on phonological acquisition because I love phonology and babies. Adam took such a naïve sentence very seriously and showed a great support. Chapters in this thesis reflect my five-year journey with Adam, which started from there; beginning from a theoretical consideration (1-year), we raised a question, ran experiments to test our hypotheses (2-year), simulated the experimental results (3-year), explored the universality of the simulation results (4-year), and finally pieces of this project were put together accelerated by meetings with Adam (5-year). Adam put all his efforts to help me at every step of this research. I will never forget our 7-hour meeting on one snowy Sunday! During my job search, Adam's late-nigh encouraging emails made me believe in myself, and his humor made me laugh and forget about my worries.

When I reflect my time with Donca Steriade, the first scene I can draw from my memory is Donca who is jumping up and down in front of a whiteboard. When things were going well, Donca showed the greatest excitement. Without her support, I could not have thought about developing my first experimental results as a bigger project. Donca also jumped up and down very much when she found analytical problems from my logic, but her criticism has always been healthy and motivated me to think as a better linguist. I learned a great deal from her, and I dare hope to catch things out of raw data as Donca someday in the future. Even after I left MIT, I still feel as if Donca is telling me "Youngah! sleep well, eat well, and exercise every day!", just as she always did at the end of our weekly meeting.

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Abbreviations

NOM	Nominative
ACC	Accusative
LOC	Locative
CON	Connective
CONJ	Conjunct
DEIC	Deictic
PRES	Present
DECL	Declarative
INTERROG	Interrogative
IMPER	Imperative
DIREC	Directive
VOC	Vocative

interview, Michael sent me a kind email telling me to 'be myself', which made me feel confident and actually that worked out! To my students, can I become a great mentor like Michael, who is so enthusiastic in discussing linguistics and at the same time who cares students with great love? I wish I could...

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I will end with the stupid trial of saying thanks to two people who first showed me how to speak. Thanks mom and dad, for everything I can imagine.

Contents

1 Why learning biases in children?

Recent experimental work has focused the role that biases play in learning phonological patterns. The role of simplicity (Moreton 2008, Pater & Moreton 2012, Seidl & Buckley 2005), and the role of phonological naturalness (Wilson 2006, Moreton 2008, Hayes et al. 2009, Becker et al. 2011, Skoruppa et al. 2011) have been investigated. For instance, Wilson (2006) provides experimental data on learning velar palatalization showing that adult learners favor changes that relate perceptually similar sounds, and proposes a naturalness bias in learning phonology.

Compared to extensive research on phonological learning biases among adults, not much is known about biases in child learners. Some experimental work has been conducted with young learners (Saffran and Thiessen 2003, Jusczyk et al. 2002, Seidl & Buckley 2005) and most of the reports about children's learning biases are from the investigation of very early acquisition stages of phonology –i.e., learning the system of sound contrasts or learning phonotactics. The next stage of phonological acquisition, namely learning patterns of alternation, has barely been a target of studying learning biases. Empirically this is partially because we do not know well which developmental stages to focus on in order to figure out biases in learning alternations. As reported in Hayes (2004), there is no concrete evidence showing when young children master patterns of alternation; Smith (1973) documents that a English-learning child failed to produce correct plurals at age 2;2; according to Berman (1985), children learning Modern Hebrew were not able to control non-concatenative morphology by four to five years of age; four-year-old child participants in Berko's (1958) wug-test normally failed to apply patterns of alternation in English plural suffixes to new items, and a similar failure was found by Baker and Derwing (1982) and Derwing and Baker (1986); very early acquisition of alternations has been observed as well, as the successful production of the Turkish accusative suffix [-a] ~ [-e] at 15 months shows (Aksu-Koç and Slobin 1985). Given the apparent large variability in the stages acquiring different morphological processes, it does not seem to be easy to determine from which developmental stage an investigation should begin.

Despite these empirical challenges, exploring biases in children learning alternations may help us understand two crucial aspects of phonological acquisition. First, children learning alternations make errors which generally show systematic patterns. For instance, children learning Brazilian Portuguese systematically extend the vowel of the 3sg indicative to the 1sg (Stoel-Gammon 1979). Spanish-learning children incorrect extend diphthongization found in the 1sg, 2sg, 3sg, and 3pl, when they produce the infinitive, 1pl, and 2pl which should appear with the non-diphthongized form of the verb. Is it really enough to understand that such errors are driven by the facts that they are "highly applicable" (MacWhinney 1978) or have high frequency, they are often "zero expression" (Jakobson 1939) or unaffixed forms, and they are morphosyntactically least marked forms (Guillaume 1927)? Such factors must play a crucial role in determining the type of children's production errors (Bybee 1985, Bybee and Brewer 1980), but I believe we can gain deeper understanding of why certain types of errors are produced, when we know more about biases in children.

Second, we observe that some phonological patterns are mastered earlier and better than others –i.e., at an intermediate stage, a child may produce adult-like forms for a certain pattern, but they may still produce erroneous forms for some other phonological pattern. A developmental sequence is sometimes independent of the facts about the primary input –e.g., frequency with which the various morphemes occur in adult speech, syllabicity, absence of homophony etc. A widely-known example is the earlier acquisition of the English past tense *–ed* alternations, and the later acquisition of the English plural suffix *–s* alternations (Berko 1958). Why is such developmental order systematically attested, which is actually opposite to what frequency by itself would have predicted ? Biases in child learners may provide a clue to understand why they go through such specific acquisition stages beyond the facts about the language input.

1.1 Biases in learning alternations

In Optimality Theory (Prince and Smolensky 1993, 2004), the approach to phonology adopted in this thesis, it has been claimed that output-to-output correspondence constraints (OO-CORR constraints, hereafter) are undominated at the initial state of morphophonemic learning (McCarthy 1997; Hayes 2004). The assumption about an *a priori* constraint ranking was originally proposed for theoretical reasons having to do with phonological learnability: without highly ranked output-to-output correspondence constraints, children have no way to learn the absence of certain patterns of phonological alternation. However, empirical evidence for the claim has rarely been provided, and then only in anecdotal form. For example, Kazazis (1969) reports one four-year-old child's errors while learning Modern Greek: the errors consist of generalizing one form of the verbal stem throughout one verb's paradigm as (1). The child innovated the illegal sequence *[xe] in the language, in the course of regularizing the verb paradigm as shown below.

(1) An error showing the high ranking status of OO-CORR constraints

['exete] 'you-pl. have', on the model of ['exo] 'I have'. (adult form ['eçete] 'you-pl. have')
(Cited by Hayes (2004:32))

Since [xe] is never found in adult speech, theoretically the markedness constraint barring the [xe] sequence should be undominated in the constraint hierarchy. However, the OO-CORR constraint regulating the [x]/[ç] distinction is initially given even higher ranking than the markedness constraints, thus the child attempts to create non-alternating paradigm. I call the initial bias given to OO-CORR constraints "the OO-CORR bias". This thesis starts with an empirical investigation on whether child learners are actually equipped with the OO-CORR bias, and then explore other learning biases in later chapters.

First of all, why do we ever need to care about the OO-CORR bias? From a narrower view, it is worth testing the validity of the assumption of an a priori constraint ranking which was originally proposed for theoretical reasons. Simply speaking, is the OO-CORR bias the actual learning mechanism that children have? If so, how do children use that tool in learning patterns of alternations? From a broader viewpoint, the OO-CORR bias implicated that child learners start to understand language as a "one-to-one correspondence between the semantic units and their phonological expression" (Bybee 1985:3) and later learn that language in reality may exhibit one-to-many relationships between meaning and sound (See Bloomfield 1933, Nida 1946, Matthews 1974 and Aronoff 1976 for proposals describing the deviations from the one-to-one correspondence between sound and meaning). If child learners start with the 'ideal' belief that each unit of meaning is uniquely associated with a phonological string, as assumed in a model like Item and Arrangement (Hockett 1954), how do they come to learn one-to-many relationships between meaning and sounds? In terms of constraints, how do children demote initially undominated OO-CORR constraints so that they can produce different surface forms in different phonological contexts?

1.2 Plan of the thesis

I first explore the question of whether OO-CORR constraints are undominated in the initial stages of learning alternations through experimental investigation. The focus is Korean noun and verb inflection. In Chapter 2, I trace the trajectory of learning alternations from the early state in which the OO-CORR bias is claimed to be robust. The experimental results provide empirical support for this mechanism: children acquire non-alternating paradigms prior to alternating ones, and they produce a wide variety of deviant forms, all of which are motivated by the persistent correspondence effect. The results further suggest that even after children are fully capable of producing adult forms with the correct alternations, they avoid producing them, in the interest of avoiding phonological alternations.

Chapter 3 provides a formal analysis of deviant production forms observed from child speakers. I show that all of the deviant forms are less optimal than the adult forms when economy of production is considered. I further show that the economy of production constraint is violated by child speakers as minimally as possible, in so far as the production of an outcome allows them to avoid alternations, and at the same time to express what they originally intended to say.

Chapter 4 focuses on the systematic way that child learners satisfy paradigm uniformity. Specifically, it is shown that children pick out the base form of the paradigms and inflect other members of the paradigm faithfully to the base form. The simulation results suggest that children choose the most reliable base form of the paradigms by comparing the phonological informativeness as well as the availability of surface forms.

Instances of alternating forms in adult speech should give children evidence to demote the initially highly-ranked OO-CORR constraints; if OO-CORR constraints stay at the top of the constraint hierarchy, alternating forms can never be produced. By means of learning simulations, Chapter 5 explores how a biased model reaches the final adult stage where OO-CORR constraints regulating alternations are demoted below the relevant markedness constraints. I show that the predictions of the models are in accordance with the learning trajectories observed in the experiments. It is demonstrated that different alternations proceed at different rates, although all followed the same trajectory of learning. This is likely due to differing amounts of phonological evidence for each alternation available to the child learners. This raises the question of what constitutes evidence for an alternation, a question I pursue in Chapter 6.

The results of artificial language learning show that learners not only generalize narrower segmental alternation patterns but also broader featural alternation patterns. The result indicates that learning of an alternation is facilitated when other featurally overlapping alternations are available in the language. The experiments also find additional biases in learning patterns of alternation: a bias against alternation itself; a bias in favor of alternations that target broader classes of segments than narrower classes of segments; a substantive bias against perceptually salient alternations. I propose a model that incorporates all of the observed biases. Chapter 7 concludes.

2 Empirical tests of the OO-CORR bias

This chapter shows that children's inflection of noun forms (§2.1) and verb forms (§2.2) in Korean deviate from adult forms in various ways, all of which better satisfy OO-CORR constraints than the correct adult forms do.

2.1 The acquisition of Korean noun paradigms

I first present patterns of alternation in Korean that learners must master. In considering the earlier stages of acquiring alternations, I pursue the hypothesis that child learners have an OO-CORR bias and this bias plays a role in acquiring phonological alternations. Predictions of the hypothesis will be laid out concerning (a) what kinds of erroneous forms learners in early acquisition stage may produce, and (b) in what order the alternations would be acquired. Two picture-description experiments test children's acquisition of Korean noun inflections and report a unified pattern of children's production across various developmental stages; inflected forms elicited from child speakers show their phonological preference to achieve paradigm uniformity. It is also shown that earlier-acquired paradigms do not involve alternation at all, or do involve some alternations that are found frequently in the language as a whole, suggesting the strong OO-CORR bias in the initial acquisition stage and the gradual demotion of OO-CORR constraints in proportion to the number of violations that learners find in the language.

2.1.1 Alternations and learning challenges

Stem-final consonants may alternate in Korean when they combine with inflectional suffixes.

Learning the inflection of sonorant-final noun stems should be relatively easy, because there is only one type of alternation, and this alternation conforms to a phonotactic restriction also seen within monomorphemic words: stem-final [l] alternates with [ɾ] when a vowel-initial suffix follows as (2), so that the surface forms obey a ban on intervocalic singleton laterals in Korean. Nasal-final nouns do not alternate; thus, paradigms with nasal-final noun stems are perfectly uniform as (3).

(2) Alternations of lateral-final nouns

/sal/ [sal] 'skin' [saɾ-i]NOM [saɾ-ɨl] ACC [saɾ-e] LOC

(3) No alternation of nasal-final nouns

/san/	[san]	'mountain'	[san-i]	[san-ɨl]	[san-e]
/sam/	[sam]	'three'	[sam-i]	[sam-ɨl]	[sam-e]
/saŋ/	[saŋ]	'table'	[saŋ-i]	[saŋ-ɨl]	[saŋ-e]

Figuring out the inflection patterns of obstruent-final stems involves challenging learning tasks. The challenge is related to the fact that Korean has a three-way laryngeal contrast between voiceless lenis, aspirated and glottalized (or tense) obstruents as shown in (4).

(4) Three-way laryngeal contrast in Korean

	Labial	Coronal			Velar
	Stop	Stop	Fricative	Affricate	Stop
Lenis	p	t	s	tʃ	k
Aspirated	p^h	t^h		$tʃ^h$	k^h
Tense	p'	t'	s'	tʃ'	k'

Voiceless lenis obstruents in Korean become voiced when intersonorant as in (5), otherwise they are voiceless. This phenomenon is found both within monomorphemic words and across morpheme boundaries. There is no allophonic variation of the feature voicing among aspirated and tensed obstruents as shown in (6).

(5) Voicing alternations of lenis obstruents

/pap/	'rice'	[pab-ɨl] ACC
/tikɨt/	'letter *t*'	[tigɨd-ɨl]
/kak/	'angle'	[kag-ɨl]
/pitʃ/	'debt'	[pidʒ-ɨl]

(6) No voicing alternations of aspirated and tensed obstruents

/sup^h/	'forest'	[sup^h-ɨl]
/pak'/	'outside'	[ak'-ɨl]

Stem-final obstruents are neutralized to voiceless lenis stops in coda position. In isolation forms, labial stops are neutralized to [p], coronal stops, affricates and fricatives to [t] and velar stops to [k]. The coda neutralization process applies without exception in Korean. Due to the coda neutralization, surface isolation forms may differ from their underlying forms and they may deviate from surface realizations found in pre-vocalic positions as well, as shown in (7).

(7) Coda neutralization of obstruent-final nouns

/sup^{h}/	[sup]	'forest'	[sup^{h}-i] NOM	[sup^{h}-ɨl]ACC	[sup^{h}-e] LOC
/nac^{h}/	[nat]	'face'	[nac^{h}-i]	[nac^{h}-ɨl]	[nac^{h}-e]
/puək^{h}/	[puək]	'kitchen'	[puək^{h}-i]	[puək^{h}-ɨl]	[puək^{h}-e]
/pak'/	[pak]	'outside'	[pak'-i]	[pak'-ɨl]	[pak'-e]

Coronal obstruents are palatalized before high front vocoids [i, j]: alveolar stops [t, t^{h}] become palato-alveolar affricates [tʃ, tʃ^{h}], and alveolar fricatives [s, s'] become palate-alveolar counterparts [ʃ, ʃ'] before high front vocoids [i] and [j]. While the latter in (9) is motivated by surface-true (inviolable) markedness constraints, the former in (8) target structures which are legal morpheme-internally; the process applies only at the morpheme boundaries between noun stems and [i]-initial or [j]-initial suffixes which directly follow the noun stem. The palatalization processes cause alternations in the noun paradigm. In (8) and (9), the surface realizations of the stem-final obstruents are [tʃ^{h}] and [ʃ] before the nominative suffix [-i], while they are [t^{h}] and [s] in other pre-vocalic forms.

(8) Palatalization in derived environment

/pat^{h}/	[pat]	'field'	[patʃ^{h}-i]NOM	[pat^{h}-ɨl]ACC	[pat^{h}-e] LOC

(9) Automatic palatalization

/pis/	[pit]	'comb'	[piʃ-i]	[pis-ɨl]	[pis-e]

Stem-final obstruents surface as their nasal counterparts, when followed by a nasal-initial suffix. As free variation between [nan-man] ~ [nam-man] 'face-only' shows in (10), stem-final coronal [t] may additionally undergo place assimilation, when a labial nasal-initial suffix follows; stem-final [n] may optionally alternate with [m] before [m]-initial suffixes. These alternations are motivated by a phonotactic requirement of nasal place agreement in Korean.

(10) Nasal alternations

/sup^{h}/	[sup]	'forest'	[sum-man] '-only'
/natʃ^{h}/	[nat]	'face'	[nan-man] ~ [nam-man]

/puəkʰ/	[puək]	'kitchen'	[puəŋ-man]
/pak'/	[pak]	'outside'	[paŋ-man]

Except for (8), the alternations from (2) to (10), occur in order to satisfy surface-true markedness constraints in Korean, such as no intervocalic singleton laterals (2), no intersonorant voiceless obstruents (5), no laryngeal features in coda positions (7), no non-palatalized coronal obstruents before high front vocoids (8), and no nasal place disagreement (10). The palatalization process in (8) occurs without exception, but the rule applies only when morpheme boundaries intervene; the alternation is limited to derived environments.

Korean noun paradigms exhibit other alternations as well, which are not motivated by inviolable phonotactic restrictions in the language. Pre-vocalic allomorphs of the obstruent-final noun stems show variation (Ko 1989, Hayes 1998, Albright 2005, 2008, Kang 2003, Kim 2005, Park 2006, Jun 2010, Choi 2004, Kang et al. 2004). For noncoronal obstruents, voiceless aspirated or glottalized stops are in free variation with their voiced lenis counterparts in prevocalic position. Adult speakers are found to prefer surface forms which realize underlying aspiration or tense value to the neutralized versions (Choi 2004, Kang et al. 2004).

(11) Stem-final noncoronal obstruent's variations

/supʰ/	[sup]	'forest'	[supʰ-i] ~ [sub-i], [supʰ-ɨl] ~ [sub-ɨl], [supʰ-e] ~ [sub-e]
/pak'/	[pak]	'outside'	[pak'-i] ~ [pag-i], [pak'-ɨl] ~ [pag-ɨl], [pak'-e] ~ [pag-e]

Stem-final coronal obstruents are expected to surface faithfully to the underlying form before vowel-initial suffixes. Besides the etymologically expected forms, however, stem-final coronal obstruents in some words are in variation with [s] as exemplified in (12).

(12) Stem-final coronal obstruent's variations

/patʰ/	[pat]	'field'	[patʃʰ-i]~ [paʃ-i]NOM	[patʰ-ɨl]~ [pas-ɨl]ACC	[patʰ-e]~ [pas-e] LOC
/k'otʃʰ/	[kot]	'flower'	[k'otʃʰ-i]~ [k'oʃ-i]	[k'otʃʰ-ɨl]~[k'os-ɨl]	[k'otʃʰ-e]~[k'os-e]

Furthermore, some coronal obstruent-final noun stems are in variation with other coronal obstruent variants as [tʃʰ, tʰ, dʒ, d] in pre-vocalic forms. Thus, as well as the etymologically expected form, and a variant ending in [s], [tʃʰ, tʰ, dʒ, d] are also observed from various coronal obstruent-final noun stems' surface realizations (Oh 2006, Jun & Lee 2007, Oh & Shin 2007, Jun 2010). Examples are given in the table below. The data in the table is taken from Jun (2010), who selected data from Kim (2003), Choi (2004) and Kang et al. (2004).

(13) Stem-final obstruent variations

Stem-final C	UR	Expected	Variants	Gloss
/t^h/	/pat^h-i/	patʃ^h-i	paʃ-i	field
	/pat^h-ɨlo/	pat^h-iɾo	pas-iɾo ~ patʃ^h-iɾo	field
	/sot^h-e/	sot^h-e	sos-e ~ sotʃ^h-e ~ sod-e	pot
	/mit^h-ɨl/	mit^h-ɨl	mis-ɨl ~ mitʃ^h-ɨl ~ mid-ɨl	bottom
/tʃ^h/	/k'otʃ^h-ɨlo/	k'otʃ^h-iɾo	k'os-iɾo ~ k'ot^h-iɾo	flower
	/k'otʃ^h-a/	k'otʃ^h-a	k'os-a ~ k'ot^h-a ~ k'odʒ-a ~ k'od-a	flower
	/natʃ^h-ɨlo/	natʃ^h-iɾo	nas-iɾo ~ nat^h-iɾo	face
	/tatʃ^h-ɨl/	tatʃ^h-ɨl	tas-ɨl ~ tat^h-ɨl ~ tadʒ-ɨl	anchor
	/totʃ^h-e/	totʃ^h-e	tos-e ~ tot^h-e ~ todʒ-e ~ tod-e	sail
	/pitʃ^h-ɨl/	pitʃ^h-ɨl	pis-ɨl ~ pit^h-ɨl	light
/tʃ/	/natʃ-ɨlo/	nadʒ-iɾo	nas-iɾo ~ nadʒ-iɾo	daytime
	/pitʃ-ɨn/	pidʒ-ɨn	pis-ɨn ~ pitʃ^h-ɨn	debt
	/moktʃətʃ-e/	mokdʒədʒ-e	mokdʒəs-e ~ mokdʒətʃ^h-e	uvula

(-i: nominative, -ɨl: accusative, -ɨlo: directive/instrumental, -ɨn:topic, -e: locative/ directive/ dative, -a: vocative)

In the literature, it has been observed that speakers have different preferences among stem-final obstruent variants (Kang 2005, Martin 1992, Choi 2004, Ito 2010, Jun 2010). Specifically, [s] is most preferred, followed by [t^h] and [tʃ^h], while [d] and [dʒ] are least preferred. Jun (2010) finds that the preference of variants matches with the lexical distribution of the final coronal obstruents in suffixed noun forms: overall [s] is most frequent in suffixed noun forms, and [t^h] and [tʃ^h] are second, followed by [d] and [dʒ] as presented below.

(14) Type frequency of lexical final coronal obstruents of suffixed forms (Jun 2010; 18)

Final-C	Frequency
s	393
t^h	253
tʃ^h	200
tʃ	32
d	0

As a variety of alternations laid out in this section indicate, children learning Korean noun paradigms are faced with the alternations motivated by surface-true (i.e., inviolable) markedness constraints, the first group in the table (15), and those that target structures which are legal morpheme-internally, the second group, as well as variations of obstruent-final nouns, the third group in (15).

(15) Alternations in Korean noun paradigms

Stem-final C	Suffixed forms	Patterns	Data
/l/	[ɾ]-V	Lateral alternation	(2)
/p,t,k,tʃ/	[b,d,g,dʒ]-V	Voicing alternation	(5)
/p,t,k,tʃ/	[m,n,ŋ,n]-Nas	Nasal alternation	(10)
/s, s'/	[ʃ, ʃ']-i	Palatalization	(9)
/t^h, t', s, s', tʃ, tʃ^h, tʃ'/	[n]-V	Coda neutralization Nasal alternation	(10)

/t, t^h/	[tʃ, tʃ^h]-i	Palatalization	(8)

/p^h, p'/, /k^h, k'/	[p^h ~ b]-V, [p' ~b]-V [k^h ~ g]-V, [k' ~g]-V	Coda neutralization Voicing alternation Variation: preference of variants faithful to the underlying forms	(5),(7)
/t^h, t', s, s', tʃ, tʃ^h, tʃ'/	[s~t^h~tʃ^h~dʒ ~d] -V(except [-i])	Variation:preference of variants reflecting lexical distribution	(12), (13)
/t^h, t', s, s', tʃ, tʃ^h, tʃ'/	[ʃ ~ tʃ^h ~dʒ]-i	Palatalization Variation:preference of variants reflecting lexical distribution	(8),(9), (12), (13)

(-V: all vowel-initial suffixes, -Nas: all nasal-initial suffixes, -i: nominative)

What knowledge must children have in order to produce alternations? Children first need to figure out the ranking of Markedness constraints >> Input-to-Output Faithfulness constraints, which reflect the phonotactics. They need to be able to find the ranking of Markedness constraints >> Output-to-Output Faithfulness constraints as well by finding out pairs of morphologically related forms that show alternations. A hypothesis about the undominated status of Output-to-Output Faithfulness constraints (McCarthy 1998, Hayes 2004) predicts two kinds of possible repairs in child production: underapplication and avoidance of alternations.

To the best of my knowledge, the acquisition of an entire system of phonological alternations of this degree of complexity has not been systematically investigated. The empirical results in this chapter will be a confirmation of this theoretical prediction. To shortly preview the results, Korean children first master alternations motivated by phonotactically inviolable markedness constraints. At the same acquisition stage, they level paradigms by innovating forms containing the sequences that are illegal in the adult language, such as non-palatalized [d] before high front vocoid-initial suffixes, violating the morphologically-conditioned palatalization process. Next, children pass through a stage in which they stop producing forms that are illegal in the adult language, but avoid producing the preferred adult forms; while children produce grammatical or legal forms in this stage, the pattern of their inflections are not yet similar to the adults' production even though they do know the correct adult forms. Notably, children in this intermediate stage innovate various deviant forms, all of which satisfy OO-CORR constraints better than adult forms do.

2.1.2 The predictions of the OO-CORR bias

Let us assume that young learners are equipped with the two major tools for learning alternations: their phonotactic knowledge (Hayes 2004) and the a priori high ranking of OO-CORR constraints (McCarthy 1997, Hayes 2004). The role of each mechanism in learning alternations will be established in the current study. I further assume, at this point, that the base of the Korean noun paradigm is the isolation (unsuffixed) form, following Albright (2008), and OO-CORR constraints are violated if phonological properties of a surface realization deviate from the base form. For instance, the alternation in (16) violates the OO-CORR constraint for voicing (OO-IDENT [(±voi)]), because its voicing feature differs form the isolation form or the base form.

(16) The evaluation of OO-CORR constraints

/ip-i/ 'leave-NOM'	OO-IDENT [(±voi)]
ibi	*
ipi	
Base : ip 'leave'	

The base status of the isolation noun form will be justified by the current experimental results, later in Chapter 4. I will show that the isolation form is the most reliable surface form, thus it is selected as the base form of the paradigms, both by adult speakers and by child speakers, who presumably have imperfect knowledge of paradigms and a smaller lexicon. For now, I focus on the learning trajectories, simply assuming that learners bring these two mechanisms –i.e., phonotactic knowledge and highly-ranked OO-CORR constraints,--to the task of learning alternations, and the OO-CORR constraints are evaluated by comparing the surface forms with the base form, the isolation form.

If all OO-CORR constraints are initially undominated, the entire set of Korean noun paradigms will be leveled at the very earliest learning state. Child learners at this initial grammar state will correctly produce the forms involving nasal-final stems, since the paradigms of nasal-final noun stems are perfectly uniform as presented in (2). All paradigms exhibiting alternations as in the table (15) will be leveled based on the output form of the isolation form or the base form: lateral alternations, voicing alternations, coda neutralizations, and nasal alternations will not be applied as in (17), if every OO-CORR constraint is undominated in early acquisition stages. I mark ★ before hypothetical errors that could be innovated by children for the purpose of paradigm uniformity.

(17) Possible innovations at the initial stage

a. Lateral-final noun stems:

/sal/	[sal]	★[sal-i] NOM	★[sal-ɨl] ACC	★[sal-e] LOC

b. Noncoronal obstruent-final noun stems:

/ap^h/	[ap]	★[ap-i]	★[ap-ɨl]	★[ap-e]

c. Coronal obstruent-final noun stems:

/pat^h/	[pat]	★[pat-i]	★ [pat-ɨl]	★[pat-e]

d. Obstruent-final noun stems:

/pap/	[pap]	★[pap-man] '-only'

Because the OO-CORR constraints are at the top of the constraint hierarchy, the paradigms are predicted to be leveled as the examples in (17) show. If a learner finds an alternation, she must demote OO-CORR constraints; otherwise, alternations continue to be blocked as in (17). Consider the simple example in (18). If the OO-CORR constraint for the feature lateral (OO-IDENT([±lat])) outranks the Markedness constraint banning laterals in intervocalic position (*[+voi][-lat][+voi]), the grammar incorrectly predicts that the candidate [sal-i] will be the winner. Only when the OO-IDENT constraint is demoted below the relevant Markedness constraint, can an alternating form be produced.

(18) Prediction of the initial constraint ranking for laterals

Base: sal /sal-i/	OO-IDENT([±lat])	[+voi][+lat][+voi]
☹ saɾ-i	*	
sal-i		*

What motivates the demotion of the OO-CORR constraints? The violation of OO-CORR constraints supported by alternation data must provide evidence to demote OO-CORR constraints. Assuming the frameworks in which constraint demotion is gradual or gradient, it is intuitive to think that the more an OO-CORR constraint is violated, the more the constraint is demoted. In adult Korean, lateral alternations, voicing alternations, coda neutralizations, automatic palatalization (i.e., [s, s']~[ʃ, ʃ']), and nasal alternations occur frequently, while palatalization occurring in derived-environment (i.e., [t, t^h]~[tʃ, $tʃ^h$]) and stem-final obstruent variations are infrequent. I will present the specific frequency of each alternation later in Chapter 5. For now, it is sufficient to note that alternations motivated by inviolable markedness constraints in Korean occur frequently, while the derived-environment alternation and stem-final obstruent variations are less frequent.

Due to the large amount of evidence showing alternations motivated by inviolable phonotactic constraints, the paradigms involving lateral alternations, voicing alternations, and coda neutralizations could be mastered as in (19) relatively early. Also, a learner can employ her phonotactic knowledge, which she has presumably acquired before entering the stage of learning alternations (Jusczyk et al. 1994, Hayes 2004, Pater & Tessier 2006) in understanding the motivation for such alternations. If a learner has already acquired Korean phonotactic rules, she realizes that the surface realizations in (17) are illegal in her language, thus they should alternate.

(19) Early-acquired alternations (expected)

a. Lateral-final noun stems:

/sal/	[sal]	[saɾ-i]NOM	[saɾ-ɨl]ACC	[saɾ-e]LOC

b. Labial and velar obstruent-final noun stems:

/ap^h/	[ap]	[ap^h-i]	[ap^h-ɨl]	[ap^h-e]

c. Obstruent-final noun stems:

/pap/	[pap]	[pam-man] '-only'		
/kas/	[kat]	[kaʃ-i]	[kas-ɨl]	[kas-e]

At this acquisition stage, derived-environment [t, t^h] ~ [tʃ, $tʃ^h$] alternations may not be correctly produced yet, since these palatalization patterns are not applied within monomorphemic words; because the process occurs in derived environment, figuring out the alternation pattern and its context is a new learning task for a learner who is starting to figure out morphology of the language. If learners have the OO-CORR bias, the leveling error of coronal obstruent-final noun stems' paradigm is predicted as shown in (20).

(20) A later-acquired alternation (expected)

Coronal obstruent-final noun stems:

/pat^h/	[pat]	★ [pat^h-i]	[pat^h-ɨl]	[pat^h-e]

Given (a) its lack of apparent phonotactic motivation, (b) a wide variety of underlying forms to surface form mappings (i.e., free variations), and (c) the low frequency of each surface realization, the acquisition of stem-final coronal obstruent nouns is expected to be delayed. The mastery of the relative preference among the variants also involves a even more challenging task—i.e., internalizing the lexical distribution of final obstruents of suffixed nouns into the learners' grammar.

If every OO-CORR constraint is initially highly ranked, learners will demote the OO-CORR constraints in accordance to the frequency of their violations by extracting overlapping features from a variety of variants [s, ʃ, t^h, d, dʒ, $tʃ^h$]. Especially in learning the alternations of coronal obstruent noun stems' alternations, this involves multiple tasks. For instance, learners demote the OO-CORR constraint for the feature [spread glottis] by accumulating the evidence provided by the alternations showing the base-final [t]'s alternation to the surface form-final [t^h] (i.e., [t] ~ [t^h]) and [t] ~ [$tʃ^h$]; the demotion of the OO-CORR constraint for the feature stridency is guided by the summed amount of alternations provided by the patterns [t] ~ [s], [t] ~ [$tʃ^h$], and [t] ~ [tʃ]. Do child learners first produce erroneous forms by leveling the paradigms in the early stages, and then produce alternating forms in the order reflecting their featural frequency in the language?

I conducted experiments to observe the patterns of noun inflection along the developmental stages. The results show strong correspondence effects in earlier stages, supporting the highly-ranked status of OO-CORR constraints in children's grammar. In later stages, patterns are observed which reflect the gradual demotion of OO-CORR constraints which matches with the availability of alternations in the language.

2.1.3 A production experiment 1

The experiment aims to elicit the inflected forms of Korean nouns, along the stages of acquiring alternations. Nothing has been reported in the literature for when and how Korean children master alternations. My informal observation of children younger than 48-months suggests that at this early stage, children do not control the patterns of alternation at all, while children older than 7-years-old attempt alternations, but still the patterns of alternations differ from adults. This seems be (surprisingly) late acquisition of phonological alternations, considering studies in other languages introduced in Chapter 1. I imagine this is due to a very high degree of complexity involved Korean nouns' alternations –e.g., a wide variety of free variation, as we examined in section 2.1.1.

I examined the inflectional patterns of Korean nouns among children from age 4 to 8. It is worth noting that the population of each age group is not identical in the current study, and each age group involves a small number of child participants. I believe, though, that it is important to ponder the systematic production patterns observed within each group, all of which provide empirical evidence for the initial OO-CORR bias.

2.1.3.1 Design

The experiment was designed to elicit the inflected forms of 30 Korean noun stems, 15 obstruent-final and 15 sonorant-final ones. All of the 30 noun stems were selected from among the most frequent 2,000 noun stems from 43,932 nouns in the Sejong corpus (Kang and Kim 2004). Nasal-final and lateral-final noun stems were included in a set of sonorant-final target nouns. The underlying segments of the stem-final obstruents were coronal, labial or velar. Due to restrictions on frequency, not all of the three-way laryngeal contrasts, introduced in (4), were involved in the target noun stems. The list of the target nouns is in (21).

(21) A list of target noun stems

a. Sonorant-final target noun stems

Nasal	san 'mountain', usan 'umbrella', an 'inside', pam 'night', kam 'persimmon', kaŋ 'river', kabaŋ 'bag', p'aŋ 'bread', paŋ 'room'
Lateral	pal 'foot', p^{h}al 'arm', ibul 'blanket' , kjul 'orange', jənpil 'pencil' , angjəŋ 'glasses'

b. Obstruent-final target noun stems

	Labial	Coronal			Velar
	Stop	Stop	Fricative	Affricate	Stop
Lenis	pap 'rice'		os 'clothes' pis 'comb' mas 'taste' s'ias 'seed'	nac 'day'	kuk 'soup'
Aspirated	ip^h 'leaf' sup^h 'woods'	pat^h 'field' sot^h 'pot'		pic^h 'light' k'oc^h 'flower'	puək^h 'kitchen'
Tense					pak' 'outside'

In order to elicit production forms of inflected noun stems, I employed a picture-description test. Participants described a picture, choosing a noun stem and its inflection of their own choice. With this design, I expected to elicit the most natural productions.

The expected inflectional forms were nominatives, accusatives, locatives, and directives. A picture including information about the target noun was presented and a sentence was given below each picture, expecting a description using one of the nominative, accusative, locative or directive forms, as shown in

(22). Except for the part that requires an inflected form of the target noun in (21), participants were given the other sentence components as inflected forms by the experimenter.

(22) An example of stimuli

Minsu-ga ______ masitk'e məkk'oitt'a.
Minsu-Nom ______ deliciously is eating.
'Minsu is eating ______ deliciously.'
expected answer: pab-ɨl 'rice-ACC'

In (22), the expected noun was *pap* 'rice', but one could describe the picture in other ways—e.g., *cəmʃim* 'lunch', *umʃik* 'food' etc. Nominative and accusative suffixes are optional in casual speech in this context, thus participants were able to produce a bare noun stem, such as *pap* 'rice' in (22), instead of the expected accusative form *pab-ɨl* 'rice-ACC'. Because the goal of the experiment was to elicit the inflected realizations of noun stems, it was ideal to reduce the chances of eliciting bare noun stems. Thus, the instruction told participants that they were required to describe pictures in formal Korean, in which speakers normally do not omit nominative and accusative case markers. In order to elicit formal Korean from children, child participants were told to say as if they presented in front of their classmates. The locative and directive suffix '-e' is not optional in Korean, thus there was no chance that a bare noun stem would be elicited in these inflected forms.

Table (23) summarizes the stem-final segments of the target nouns along with their frequencies: for example, the number 3 in the cross between 'Nominative' and 'Nasal' indicates that there were three stimuli in which the participant was encouraged to produce a nasal-final noun stem with nominative marking; the number 1 in the intersection between 'Velar' and 'Accusative' indicates that there was one stimulus in which a velar-final noun stem -underlyingly ending with /k^h-/ was targeted with accusative inflection.

(23)

Stem-final segment	Sonorant		Obstruent		
	Nasal	Lateral	Labial	Coronal	Velar
Nominative	3	2	1 (/p^h/)	3 (/t^h, s, tʃ/)	1 (/k/)
Accusative	3	2	1(/p/)	3 (/t^h, s, tʃ^h/)	1(/k^h/)
Locative	3	2	1(/p^h/)	3 (/s, tʃ/)	1(/k'/)

Pictures were either taken from websites with permission, or designed as colored illustrations for the current test by a graduate student at the MIT Media Lab. I first obtained 75 pictures and asked three Korean adult speakers to describe the pictures in written form. They were asked to fill the blank in a sentence as in (22) in whatever way they wanted to describe a given picture. Among the 75, I selected 30 pictures that all three adult speakers described with the identical noun stem. In this way, I expected to limit the diversity of lexical choices as much as possible.

2.1.3.2 Procedure

The test was designed as a web-based experiment using Google documents. Adult participants and the parents of child participants were sent the link to the online experiment. Each participant accessed the experiment individually. No time limit was imposed, but they were told to complete the test in a single session. Adults and children were asked to give their answers orally and the answers were recorded during the test using the internal microphones of each participant's computer. I asked the parents not to give their children response-contingent feedback. Before the test session, participants were given three examples, to allow them to get acquainted with the form of the test. In order not to show an alternation of noun stems, examples in the instruction were chosen from non-alternating vowel-final noun stems.

2.1.3.3 Participants

Eleven native Korean children aged 4;6-8;2 participated in the experiment. For comparison, eight adult native Korean speakers also participated. Ten children were studying in regular kindergartens in Seoul and the oldest child (aged 8;2) had attended an elementary school for nine months. All adult participants were standard Seoul Korean speakers. Because the experiment required participants to read sentences in Korean, I confirmed that all child participants could read the Korean alphabet prior to the test.

2.1.3.4 Results

For 19 out of 30 stimuli, all child and adult participants described the picture using identical noun stem forms, and those were the stems that the experimenter intended to elicit. I will call those noun stems 'target noun stems'. I first present the inflectional patterns of the target noun stems, and then report the patterns found among non-target noun stems.

The nineteen nouns that were consistently selected across all participants involved 11 sonorant-final and 8 obstruent-final ones. Sonorant-final nouns were elicited in 3 nominative forms, 5 accusative forms, and 3 locative or directive forms. Neither child nor adult participants omitted suffixes in inflecting sonorant-final nouns, following the instructions. The elicited template of noun inflection is given in (24) with examples.

(24) The template of sonorant-final nouns' inflection

Stem-{NOM[-i], ACC[-ɨl], LOC/DIREC[-e]}

p^haɾ-i 'arm-NOM', jənp^{h}iɾ-ɨl 'pencil-ACC', paŋ-e 'room-LOC'

The alternation of sonorant-final nouns conformed to adult usage: both child and adult participants always faithfully realized stem-final nasals in inflected forms, and they correctly changed stem-final [l] to [ɾ] in intervocalic positions with no exception. The list of elicited inflected forms of sonorant-final nouns is given in (25).

(25) The list of inflected forms of sonorant-final nouns

a. Stem-NOM

/pam/ [pam-i] 'night', /p^hal/ [p^haɾ-i] 'arm' /pal/ [paɾ-i] 'foot'

b. Stem-ACC

/usan/ [usan-ɨl] 'umbrella', /kabaŋ/ [kabaŋ-ɨl] 'bag' /angjəŋ/ [angjəŋ-ɨl] 'glasses'

/jənpil/ [jənpiɾ-ɨl] 'pencil', /ibul/ [ibuɾ-ɨl] 'blanket'

c. Stem-Loc/Direc

/san/ [san-e] 'mountain', /kaŋ/ [kaŋ-e] 'river' /paŋ/ [paŋ-e] 'room'

Eight obstruent-final nouns were elicited –3 labial-final stems, 3 coronal-final stems, and 2 velar-final stems. Lenis and aspirated obstruent-final stems were elicited, but no glottalized (tense) obstruent-final stem was produced by any participant although it was included in the set of target noun stems. Obstruent-final noun stems were elicited in 3 nominative forms, 3 accusative forms, and 2 locative or directive forms. The list of the elicited obstruent-final nouns in each inflected form is given in (26).

(26) The list of obstruent-final stems produced consistently by all participants

a. Nominative
/ip^h/'leaf', /os/ 'clothes', /natʃ/ 'day'
b. Accusative
/pap/ 'rice', /pis/ 'comb', /k'oc^h/'flower'
c. Locative
/pat^h/'field' /puək^h/ 'kitchen'

Unlike for sonorant-final nouns, which both adults and children inflected in the identical template in (24), the patterns of obstruent-final nouns' inflection were different depending on participants' age. I first report the results of adults.

Adults always suffixed obstruent-final noun stems, just as they did for sonorant-final noun stems. For noncoronal obstruent-final noun stems, the underlying stem-final voiceless lenis stop alternated to the corresponding voiced one without exception –e.g.,/pap-il/ to [pab-il] 'rice-ACC'. Underlying stem-final aspirated labial and velar obstruents are in variation with neutralized lenis stops –e.g., /ip^h/ alternated with [ip^h-i] ~ [ib-i] 'leave-NOM', and /puək^h/ with [puək^h-e] ~ [puəg-e] 'kitchen-LOC'. The faithful realization of underlying stem-final /p^h/ and / k^h/ were predominant compared to the realization of voiced lenis counterparts [b] and [g]. The frequency of each variant depending on its underlying form is given in (27). The empty cells indicate that no form was elicited in that inflection form for the segment.

(27) Alternations of stem-final noncoronal obstruents from adults[1]

Stem-final C	Suffix	[b]	[p^h]	[g]	[k^h]
/p/	-il	8 (100%)	0		
/p^h/	-i	3 (37.5%)	5 (62.5%)		
/k^h/	-e			2 (25%)	6 (75%)

[1] Because participants were able to choose any noun stem and its inflection pattern was their own choice, the labial obstruent was elicited only in nominative and accusative forms, and the velar obstruent in /puək^h/ 'kitchen' only in a locative form.
[2] In presenting the results, I do not apply the automatic palatalization process, [s] to [ʃ] before [i], in phonetic transcription. Elicited data show that the process was always correctly applied.
[3] Informal observation of production by Korean adults suggests that this structure improves when the suffix is only on the later phrase. In that case, suffixation is interpreted as a topic marking. However, such

For coronal obstruent-final noun stems, four of the coronal obstruent variants [s, tʰ, tʃʰ, dʒ][2] were observed, as it has been widely reported in the literature (see Jun (2010) for literature review). [s] was the most preferred variant across all inflected forms, followed by [tʃʰ], [tʰ] and [dʒ]. A variant [d] was not elicited in this experiment. Underlying /s/ always surfaced faithfully. However, /tʃ, tʃʰ, tʰ/ frequently mapped to unfaithful variants, and the most preferred unfaithful surface form for the stem-final /tʃ, tʃʰ, tʰ/ was [s]. The variants of each underlying segment are given in (28).

(28) The frequency of variants of underlying stem-final consonants

Stem-final C	Suffix	[s]	[dʒ]	[tʃʰ]	[tʰ]
/s/	-i	8 (100%)	0	0	0
	-ɨl	8 (100%)	0	0	0
/tʃ/	-i	5 (62.5%)	2 (25%)	1 (12.5%)	1 (12.5%)
/tʃʰ/	-ɨl	2 (25%)	0	5(62.5%)	1 (12.5%)
/tʰ/	-e	3 (37.5%)	0	1(12.5%)	4 (25%)
Total		26	2	7	6

For /tʃ/, the elicited frequency of [s] outnumbered [dʒ]. /tʃ/ was occasionally produced as [tʃʰ] or [tʰ], /tʃʰ/ to [tʰ], and /tʰ/ to [tʃʰ]. No underlying form except for /tʃ/ was mapped to [dʒ].

The alternation patterns of obstruent-final nouns from adult speakers are summarized as follows:

(29) Variatility of obstruent-final nouns from adults

a. Noncoronal obstruent-final nouns alternated with their aspirated counterparts, when underlying forms involve aspirated obstruents.

b. Coronal obstruent-final nouns alternated with [s, tʃʰ, tʰ, dʒ].

c. [s] was the most preferred variant among all inflected forms, [tʃʰ, tʰ] were in the middle, and [dʒ] was least preferred.

d. Underlying forms were not always faithfully realized. /s/ always preserved its underlying properties in the surface form, while others are likely to be realized as [s].

Children's inflection patterns of obstruent-final nouns differ from those of adults. Furthermore, the patterns are significantly different within the child group, depending on their developmental stages. Based on the patterns of inflection, I classify the child participants into three age groups.

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[2] In presenting the results, I do not apply the automatic palatalization process, [s] to [ʃ] before [i], in phonetic transcription. Elicited data show that the process was always correctly applied.

The youngest group involves three children aged from 4;6 to 5;4. They always employed the template in (24) in inflecting obstruent-final nouns. The correct nominative, accusative and locative or directive suffixes, '-i', '-ɨl', and '-e', were selected.

All obstruent-final nouns always surfaced as voiced lenis stops in this age group: they produced stem-final noncoronal obstruents as [b] and [g], and stem-final coronal obstruents as [d], a pattern which was not observed at all among adults.

(30) Patterns of obstruent-final noun stems from the youngest children

a. Noncoronal obstruent-final noun stems:

/ip^h/'leaf' [i$\underline{b}$-i], /$puək^h$/ 'kitchen' [puə$\underline{g}$-e]

b. Coronal obstruent-final noun stems:

/os-i/ 'clothes' [o$\underline{d}$-i], /nac-i/ 'day' [na$\underline{d}$-i], /pis/ 'comb' [pi$\underline{d}$-i], /$k'oc^h$/ 'flower' [ko$\underline{d}$-ɨl], /pat^h-e/'field' [pa$\underline{d}$-e]

Very different inflection patterns were found from the older group of children. I will call this age group 'the intermediate group'. This group involves six children aged from 5;1 to 7;3. Notably, children in this group did not always employ the inflectional template in (24). Recall that the instructions told participants to use formal Korean by which we expected to elicit the template in (24), and that all adult participants employed the expected template in all of their answers. The same was true for the children in the youngest group. Thus, the use of different inflectional templates is specific behavior that we observed from the intermediate group children. Also, such a pattern was found especially when children inflected nouns ending in coronal obstruents, but was not frequent at all when they produced inflected forms of sonorant-final or noncoronal obstruent-final noun stems.

When children in this group used the template in (24), the patterns of stem-final segments' alternations were as follows. Nasal-final noun stems were faithfully realized and stem-final [l] alternated with [ɾ] when a vowel-initial suffix follows; both of the sonorant-final noun stems surfaced in correct adult forms. For noncoronal obstruent-final noun stems' alternations, the proportion between faithful and neutralized realizations of underlying values is different from that observed from adults. Considering the adults' results in (27), the overall proportion of voiced lenis stops in surface forms is larger than their aspirated counterparts in the intermediate group. As shown in the table (31), the higher proportion of voiced lenis stops in this group is due to the higher frequency of the unfaithful realization of aspirated noncoronal obstruents: while adults alternated /p^h/ with [b] 37% and /k^h/ with [g] 25 %, the proportions observed from this age group were 67% and 83 % respectively. While adults never alternated unaspirated voiceless noncoronal obstruent /p/ with aspirated [p^h] as in (27), children in this group occasionally mapped /p/ to [p^h].

(31) Alternations of noncoronal obstruents from children in the intermediate group

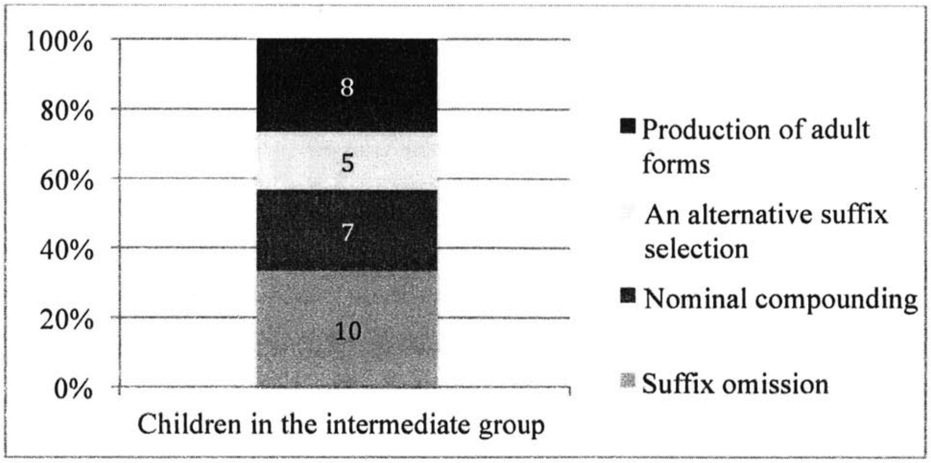
Stem-final C	Suffix	[b]	[p^h]	[g]	[k^h]
/p/	-ɨl	4 (67%)	2 (33%)		
/p^h/	-i	4 (67%)	2 (33%)		
/k^h/	-e			5 (83%)	1 (17%)
Total		8	4	5	1

In spite of proportional differences of variants compared to adults, children in the intermediate group frequently employed the inflectional template that adult speakers use and they applied proper alternation patterns to noncoronal obstruent-final as well as sonorant-final noun stems' inflection when employing the inflectional template.

Children in the intermediate group also employed different inflectional templates than the one in (24). They did use the adult-like template in (24) in their production for most of the cases for 83 out of the total number of their answers, 114, but these additional templates were observed as well for 31 out of 114 cases. Let us call the inflectional templates that were observed among the intermediate group children 'deviant templates'. Deviant templates are grammatical in the language, but were not preferred at all among adult speakers in the current experiment. I will come back to this issue in the following discussion section.

Remarkably, deviant templates were observed frequently when the intermediate group children inflected coronal obstruent-final nouns (22 out of 31), but relatively infrequent when they inflect sonorant-final or noncoronal obstruent-final nouns (9 out of 31). Three types of deviant templates are as follows: first, they omitted nominative or accusative suffixes; second, they created a nominal compound involving a target noun, when a single noun stem would have provided an otherwise adequate description; third, they used an alternative suffix which adds the animacy to the intended referent. The proportion of each template among children in this group's production is provided in the graph (32). The graph below shows the result of coronal obstruent-final nouns' inflection, without including sonorant-final and noncoronal obstruent-final nouns' inflection from which we did not observe the use of deviant templates. Adult forms in the graph (32) indicate the adult-template of inflection presented in (24).

(32) The frequency of each type of coronal-final nouns' inflectional patterns



At this stage, children never produced illegal forms in the adult language; they no longer produced the form [d-i], which violates a derived-environment palatalization rule in Korean described in (8). However, their choice of inflectional templates deviated from adults in various ways, as shown in the graph above. Crucially, three deviant templates in the graph, suffix omission, nominal compounding and an alternative suffixial choice, involve a stem-final [t] or [d], but no other coronal obstruent variants. I report each inflectional pattern in detail below.

First, 37% of coronal obstruent-final nouns' inflection omitted the case markers that are optional in adult casual speech –i.e., nominative and accusative markers. Adults never omitted case markers, following instructions. Children in this group never omitted suffixes in inflecting sonorant-final noun stems or noncoronal obstruent-final noun stems, either. Only when they inflected coronal obstruent-final suffixes did they frequently produce unsuffixed nouns. An example comparing an adult and a child answer is given in (33). As shown, the child form exhibits the stem-final [t] which is identical with the stem-final segment found in the isolation form, while the adult form involves a [t] ~ [s] alternation.

(33) Suffix omission

a. Adult 1: Mina-ga <u>k'os-ɨl</u> angoitt'a.

b. Child 8: Mina-ga <u>k'ot</u> angoitt'a.

Mina-NOM flower(-ACC) is holding.

'Mina is holding a flower.'

At this same intermediate stage, child participants created nominal compounds, in which a target noun serves as a complement of a node denoting a quality. Examples are given in (34). Again, the production involving nominal compounds was observed only from children in the intermediate stages, and only when they inflected coronal obstruent-final nouns. In the two examples in (34), nominal compounds are underlined. Because a suffix is added at the right edge of the compound, the target nouns within the compounds were not suffixed. Thus, nominal compounds involve the isolation form of the target nouns, which ends in [t], or [d] when a vowel-initial noun stem follows.

(34) Nominal compounding

a. Adult 1: i os-i p'algat^{h}a.
this clothes-NOM is red.
'This clothes is red'.
b. Child 8: i ot sek-i p'algat^{h}a.
this clothes color-NOM is red.
'The color of this clothes is red.'

a. Adult 1: Mina-ga k'os-ɨl angoitt'a.
Mina-NOM flower-ACC is holding.
'Mina is holding a flower.'
b. Child 10: Mina-ga k'ot han songi-il angoitt'a.
Mina-NOM flower one stem-ACC is holding.
'Mina is holding a stem of flower.'

Third, some instances of using an alternative suffix were found, where the use of locative or directive suffix was expected. Children occasionally selected a locative or directive suffix *–hant^{h}e*, that was not chosen by adults. Adults always chose *–e* for the locative or directive suffix, which is compatible with an inanimate. For instance, Korean grammar requires that a location such as *san* 'mountain' be suffixed with *–e*, because the noun to which *–e* suffixes is an inanimate. However, some productions elicited from children in this intermediate group showed the use of a suffix *–hant^{h}e*, which is compatible with an animate but not with an inanimate referent. For example, an animate such as a person is suffixed with –*hant^{h}e*, meaning 'to or toward the person', but children in this group used *-hant^{h}e*, when the referent is an inanimate, such as mountain. As a result, the animacy is added to the referent, as if it is alive. Such style of speech is actually found from child-directed speech or fairytales intended for child readers. An example using the suffix - *hant^he* is given below. As shown, children's production form show the use of the stem-final [t] found in the isolation form of coronal obstruent-final nouns, while adult forms involve an alternation of [t] with [t^h].

(35) An alternative suffix selection

a. Adult 1: Junsu-ga pat^h-e itta.
Junsu-NOM field-LOC is.
'Junsu is in the field'

b. Child 7, 9, 10, 11, 13: Junsu-ga pat-hant^he itta.
Junsu-NOM field-ANIMATELOC is.
'Junsu is in the field.'

Along with the three deviant forms, suffix omission, nominal compounding, and an alternative suffix selection, children occasionally employed adult forms (8 out of 30) when they inflected coronal obstruent-final nouns, as shown in the graph (32). Variants of coronal obstruents were observed, and the predominant variant across all suffixed forms was [s]. Compared to the adults' result in (28), underlying forms barely surfaced faithfully; each underlying stem-final segment of coronal obstruents were predominantly mapped to [s].

(36) Stem-final coronal obstruent variants from children in the intermediate group

Stem-final C	Suffix	[s]	[dʒ]	[$tʃ^h$]	[t^h]
/s/	-i	6 (100%)	0	0	0
	-ɨl	6 (100%)	0	0	0
/tʃ/	-i	5 (83%)	2 (33%)	1 (17%)	1 (17%)
/$tʃ^h$/	-ɨl	4 (67%)	0	1(17%)	1 (17%)
/t^h/	-e	4 (67%)	0	0	2 (33%)
Total		25	2	2	4

There were two children who showed different production patterns from those we have considered so far, and there were systematic inflection patterns observed from two children. I will call them 'the oldest group'. The oldest group of children involved two participants aged 8;0 and 8;2. Both children always used nominal suffixes, as instructed: they employed the adult-like template in (24), with no exception. This is a different pattern from children in the intermediate group, who occasionally employed deviant templates especially when they inflected coronal obstruent-final noun stems. As all other child participants, they also did not produce any error when they inflected sonorant-final noun stems; nasal-final ones were faithfully realized and lateral-final ones correctly underwent flapping when a vowel-initial suffix followed. For noncoronal obstruent alternations, aspirated stops and their voiced lenis counterparts were observed. The distribution of aspirated and voiced lenis stops was different from the pattern observed in the adult group, in that the voiced lenis stops were predominantly elicited, regardless of the underlying forms, as shown in (37). This is a similar pattern to which we observed from other two child groups.

(37) The alternation of noncoronal obstruent-final nouns from oldest children

Stem-final C	Suffix	[b]	[pʰ]	[g]	[kʰ]
/p/	-ɨl	2 (100%)	0		
/pʰ/	-i	1(50%)	1 (50%)		
/kʰ/	-e			2 (100%)	0
Total		3	1	2	0

For coronal obstruent-final nouns, children in this age group neither produced an illegal form [d-i] as the youngest children did, nor employed deviant templates that were observed from children in the intermediate group. Every coronal obstruent-final noun was inflected using the adult-like inflectional template, and they show alternations. From all underlying coronal obstruent-final segments, the [s] variant was most preferred, and this is true across all inflected forms including nominative, accusative and locative or directive forms. The distribution of variants depending on each underlying value is illustrated in (38). Since no systematic pattern was observed depending on different suffixes, I will report the result without distinguishing different suffixed forms.

(38) Stem-final coronal obstruent variations from oldest children

Stem-final C	Suffix	[s]	[dʒ]	[tʃʰ]	[tʰ]
/s/	-i	2 (100%)	0	0	0
	-ɨl	2 (100%)	0	0	0
/tʃ/	-i	2	0	0	0
/tʃʰ/	-ɨl	1 (50%)	0	1(50%)	0
/tʰ/	-e	1 (50%)	0	0	1 (50%)

So far we have observed the inflectional patterns of 19 stimuli out of 30, where all participants used the target nouns in picture descriptions. I left out 11 stimuli, where at least one of the participants employed non-target noun stems. Every participant described pictures at least once using a non-target noun. Eight adult speakers participated in the experiment and each used non-target nouns for between four and nine pictures out of 30 in total. Inspection of the stimuli for which adults used non-target nouns did not show any systematic phonological property of the target nouns; 59% of the target noun stems that were targeted for alternative lexical choices were sonorant-final ones, and 41% were obstruent-final ones. In other words, adult participants produced the different noun stems than the ones expected by the experimenter (and three adult speakers who gave the written descriptions of the pictures before conducting the experiment), not because of phonological properties involved in the alternations of the target nouns, but because of different reasons such as a different preference of certain lexical items over others or a different interpretation of the given stimulus.

Among children, however, alternative lexical choices systematically targeted coronal obstruent-final nouns. This tendency was the same across all three child groups, thus I report the result without distinguishing specific developmental stages of child participants. The list in (39) shows which target nouns children did not use in describing pictures and which corresponding nouns they actually chose in their production. For instance "*mas* 'taste' → *kan* 'flavor' means that the experimenter expected participants to use *mas* 'taste' in describing a picture but child participants described the picture using the noun stem *kan* 'flavor'. As shown, many of the target nouns that children did not choose were obstruent-final nouns. The alternatively selected lexical items were overwhelmingly toward non-obstruent final nouns; vowel-final noun stems, which do not alternate at all, or sonorant-final noun stems, which either do not alternate when nasal or does alternate with [ɾ] when lateral. The pairs of target noun stems and elicited ones are presented in (39).

(39) Alternative lexical choices

sup^h 'woods' → namu 'tree', namutul 'trees', san 'mountain', millim 'wild woods'
sot^h 'pot' → kɨɾɨs 'jar', nembi 'pot'
mas 'taste' → kan 'flavor'
s'ias 'seed' → s'i 'seed'
pic^h 'light' → he 'sun', cul 'line'
kuk 'soup' → kuŋmul 'soup', tjəncaŋ 'soy-bean soup'
pak' 'outside' → pakk'at^h 'outer side', nəmə 'over'
an 'inside' → paŋ 'room' kaunde 'middle', cuŋaŋ 'middle', sok 'inside'
kam 'persimmon' → kwail 'fruit'
paŋ 'room' → an 'inside'
kjul 'orange' → olenci 'orange', kwail 'fruit'

The observations about the stem-final consonants' inflection in the three child groups are summarized as follows:

(40) Summary of noun inflection from children

All three groups

a. Sonorant-final nouns were inflected just as adults.

b. Noncoronal aspirated obstruents were in variation with their voiced lenis counterparts, but underlying aspirated obstruents were more frequently neutralized than adults.

c. Alternative lexical items were chosen mostly from the ones that do not exhibit alternation or exhibit lateral alternation.

For coronal-final noun stem's inflection;

The youngest group (4;6-5;3)

a. Stem-final [t] always alternated to [d], and the illegal [d-i] sequence, which violates the palatalization rule in Korean, was observed.

The intermediate group (5;1-7;3)

a. Inflectional suffixes were omitted, resulting in the use of [t] or [d].

b. Nominal compounds involving a coronal-final noun were created, resulting in the use of [t] or [d].

c. An alternative suffix was selected, resulting in the use of [t] or [d].

d. Adult inflectional forms were found, with [s] as the dominant variant.

The oldest group (8;0-8;2)

a. Adult inflectional forms were found, with [s] as the dominant variant.

2.1.3.5 Discussion

Adult data in the current experiment shows that speakers internalized the distribution of lexical final obstruents in noun stems and use the knowledge in their productions. As noted by Jun (2010), most of the obstruent-final stems had variants, besides the standard faithful output of the underlying form that is reflected in the written form, and the observed relative preferences among variants are in accordance with the lexical statistics shown in table (14).

The child data suggest that as early as age 4, Korean children successfully produce alternations involving sonorant-final noun stems and noncoronal obstruent-final noun stems. While the distribution of variants among noncoronal obstruent-final noun stems, aspirated and voiced lenis stops, was different from that of adults, the types of alternating forms that they produced were the ones found in the adult language. At the same stage, however, they produced inflected forms of coronal obstruent-final noun stems which is not found in the adult language at all—i.e., inflected forms involving the stem-final [d] variant. These child forms are illegal before the nominative suffix [-i] because it violates the morphologically-conditioned palatalization process in Korean. However, all of their productions involving [d] variants are more faithful to the base form of coronal obstruent-final nouns' paradigms (i.e., isolation forms ending in [t]) than adult forms involving stem-final [s, t^h, $tʃ^h$, dʒ] do: it is just the feature voicing that alternates from the stem-final [t] to [d] in child forms, but various multiple featural changes are involved from the stem-final [t] to adult variants [s, t^h, $tʃ^h$, dʒ].

If we do not assume that children are equipped with highly ranked OO-CORR constraints at the initial state of phonological acquisition, children's inflection patterns described in the above paragraph are hard to understand. Given that none of the adult variants —i.e., [s, t^h, $tʃ^h$, dʒ], was produced by children in the early stages, OO-CORR constraints relevant to the alternation from stem-final [t] to [s, t^h, $tʃ^h$, dʒ] must be highly ranked in children's grammar, and thus block the production of the variants.

Children changed the stem-final [t] of the isolation form of coronal obstruent-final nouns to [d], and this alternation is not found in the primary input. This result suggests that the OO-CORR constraint for the feature voicing was undominated as other OO-CORR constraints, but it is demoted in the very early stages of learning alternations. If every OO-CORR constraint starts equally ranked in the initial constraint ranking, is there any reason to believe that the OO-CORR constraint for voicing is demoted before others?

The earlier demotion of the OO-CORR constraint for voicing seems to be reasonable, when we consider the frequency of alternations. Counts of Korean inflectional suffixes from the database that Albright (2006) created based on the Sejong corpus reveal that vowel-initial suffixes are most frequent among the ones appearing directly after the noun stems. As introduced in section 2.1.1, voiceless lax obstruents become voiced when prevocalic. Stem-final voiceless lenis obstruents such as [k] and [p] are very frequent in Korean, as the count of the stem-final segments of Korean nouns from the Sejong Corpus of written Korean shows in (41). As shown, [t]-final nouns are not represented at all, thus they do not provide any evidence of the voicing alternation found before vowel-initial suffixes. However, due to the large number of voicing alternation of stem-final voiceless lenis obstruents [k] ~ [g] and [p] ~ [b] triggered by highly frequent vowel-initial suffixes, learners find many tokens which provide evidence to demote the OO-CORR constraint for the feature voicing, and thus generalize the pattern to the inflection of [t]-final noun stems as well.

(41) The distribution of stem-final segments of Korean noun stems

o	6,504
k	6,028
n	5,919
l	4,819
a	3,780
i	3,478
m	2,582
u	2,040
u	1,994
ɑe	1,820
p	1,469
e	1,346
jə	969
s	393
t^h	253
$tʃ^h$	200
ɨ	176
k^h	73
p^h	42
tʃ	32
k'	19
t'	2
h	1
t	0
Total	43,932

The result that children did change lateral-final noun stems suggests that the OO-IDENT constraint for the feature lateral is already demoted in the early stages as well. This can also be accounted for as the result of early demotion of the OO-CORR constraint for the feature lateral due to large number of lateral alternations in Korean, since lateral-final nouns are the fourth largest class in Korean noun paradigms, as shown in the table above.

The two surface forms of noncoronal obstruent nouns' inflections from children are same as the adult forms, though the proportion of the two forms are different in different age groups: stem-final noncoronal obstruents /p^h/ and /k'/ are realized as [b, p^h] and [g, k'] in pre-vocalic positions. The surface forms [b] and [g] from /p^h/ and /k'/ in prevocalic positions provide additional support for the claim that OO-CORR constraints for the feature voicing are demoted in children's grammar at a very early stage. The underlying aspiration values in /p^h/ and /k^h/ are more faithfully realized in later acquisition stages. This result can be understood in two different ways. First, younger children might not have figured out the correct underlying forms, and the stem-final /p^h/ and /k^h/ could be wrongly encoded as /p/ and /k/ in their grammar, which are realized as [b] and [g] as the result of voicing alternation. Given that unsuffixed forms, whose stem-final segments are [p] and [k], are most frequent in child-directed speech in Korean (Choi 2001), it seems plausible that children might have incorrectly consider the majority of stem-final noncoronal obstruents as /p/ and /k/. Second, if children know the correct underlying forms ending in /p^h/ and /k^h/, the high frequency of mapping /p^h/ and /k^h/ to [b] and [g] from children could be due to the lower ranking of input-to-output correspondence constraint for the feature [spread glottis] in their grammar. The current data is insufficient to tell if children correctly figured out the underlying forms of noun stems or not. This needs further investigation.

For the inflection of coronal obstruent-final nouns, [s] was the predominant variant in the oldest group. This tendency was also found from some children in the intermediate group. Potentially, the adult preference for [s] across all suffixed forms has a greater effect on the production of children at these stages.

Children in the intermediate group always conformed to inviolable markedness constraints; their productions always satisfied the palatalization rule of Korean which was frequently violated by children in the youngest group. Presumably, this is because the intermediate group children have processed enough evidence to acquire the palatalization process for stops. Even though children in this group never produced incorrect inflected forms, they employed various strategies for inflect coronal obstruent-final nouns. The forms that they produced often showed alternative morphological structures, which systematically exhibit stem-final [t] or [d], indicates that the tendency children use stem-final [t] or [d], which are more faithful to the stem-final segment's property of the isolation form [t] than the adult variants [s, tʃ, $tʃ^h$, dʒ] do. The pattern they produced for coronal obstruent-final nouns' inflection were grammatical, but involve suffix omission, embedding the noun as the compliment of a complex NP compounding, an alternative suffix selection or alternative lexical choices, patterns which were not found from adult participants. Children in the intermediate stages hardly produced such patterns when they inflected forms of sonorant-final nouns or noncoronal obstruent-final nouns. Also 8 out of 30 inflections of coronal obstruent-final nouns from children in this stage show the use of adult-variants, as shown in (32).

The deviant structures were only found in the inflected forms of coronal obstruent-final nouns, where stem-final variation occurs. Given that children in this stage produced nouns using the adult-like inflectional template when they inflected sonorant-final nouns and noncoronal obstruent nouns, they seem to know the preferred adult structure of noun inflection: a noun stem followed by an inflectional suffix. However, instead of inflecting nouns in adult forms, they omitted suffixes, substituted suffixes or created nominal compounds. Additionally they sometimes avoided alternations altogether by selecting alternative lexical items. Then why do they still deviate from adults by employing these various strategies, even though they seem to know how to inflect nouns in adult-like forms?

The hypothesis I pursue is that such production patterns are driven by children's phonological preferences: in the interest of obeying OO-CORR constraints which are given high weights in their grammar, they avoid some alternations even though they know the patterns of alternations. All the strategies employed by children in the intermediate group allow them to not use variants [s, t^h, dʒ, $tʃ^h$], but instead use stem-final [t] which is found as the stem-final segment of isolation forms, or [d] which differs minimally from stem-final segment of the isolation forms.

I conducted an additional experiment, which tests whether the observed children's behaviors in Experiment 1 are indeed driven by their phonological preferences. Though Experiment 1 already seems to provide strong evidence that children know how to correctly alternate coronal obstruent-final nouns but they want to avoid alternation, it is worth checking whether the observed production pattern was rooted in the initial OO-CORR bias. First of all, we need robust empirical evidence supporting the OO-CORR bias, which has rarely been proven to be an active learning mechanism in phonological acquisition. Also, this data is not a standard type of child production patterns that can be normally found in the acquisition literature. As noted, the forms that they produce are grammatical in the language, but some of their inflections, such as noun compounds, are morphologically more complex, which is very different from most of erroneous forms reported in acquisition work. Is it really because of the initial OO-CORR bias that children employed deviant inflectional templates which sometimes involve greater levels of morphological complexity?

If children had employed various repair strategies in the interest of avoiding alternations in this experiment, even though they know how to alternate coronal obstruent-final nouns, in a condition where they do not have an option to employ a deviant inflectional template, they will use the adult-like template which requires them to alternate coronal obstruent-final nouns by suppressing their phonological preference.

2.1.4 A production experiment 2

The goal of Experiment 2 is to see if children are able to alternate coronal obstruent-final nouns before a vowel-initial suffix, by providing a situation to speakers in which coronal obstruent-final nouns must alternate. If under this controlled setting children are found to successfully produce alternating forms of coronal obstruent-final nouns, then the observed child behaviors in Experiment 1, the deviations by which they do not need to alternate noun stems, can be justified as the result of phonological avoidance of alternations in order to obey the highly ranked OO-CORR constraints.

I expected to elicit alternating forms of obstruent-final noun stems by imposing a syntactic constraint of Korean to the sentence that speakers are supposed to produce. The idea behind this experimental design is as follows. Korean syntax requires parallel structure between coordinated phrases. For instance, if a noun phrase has an overt suffix, the noun phrase it is coordinated with in a sentence must also have an overt suffix; if a case marker is omitted in one phrase, the other coordinated noun phrase in the sentence must not have a case marker either. Case marking on only one phrase in a coordinated sentence is not completely ungrammatical but very unnatural and rarely observed in native speakers' utterances. If a noun phrase involves a nominal compound, the coordinated noun phrase also involves a nominal compound. It is unnatural if a compound and a bare noun stem coordinate. Natural and unnatural coordinated structures in Korean are summarized in (42).

(42) A syntactic constraint on Korean nominal coordinate clauses

a. Noun-CASE, Noun-CASE

b. Noun, Noun

c. ??? Noun-CASE, Noun or ???Noun, Noun-CASE

d. [Noun-Noun]-CASE, [Noun-Noun]-CASE

e. ??? [Noun]-CASE, [Noun-Noun]-CASE or ??? [Noun-Noun]-CASE, [Noun]-CASE

An example showing the requirement of suffixation in both clauses or neither of the coordinated clauses, (a) to (c) in (42), is given below.

(43) A sentence involving nominal coordinated phrases

a. Minsu-ka pap(-ɨl) mək-k'o, Gunwoo-ka kam(-ɨl) mək-nɨn-da.

b. Minsu-NOM rice(-ACC) eat-and, Gunwoo-NOM persimmon(-ACC) eat-PRES-DECL.

Minsu is eating rice and Gunwoo is eating a persimmon.

c. ??? Minsu-ka pab-ɨl mək-k'o, Gunwoo-ka kam mək-nɨn-da[3].

I employed this syntactic constraint, 'parallel templates of coordinated phrases', to elicit alternating forms of coronal obstruent-final noun stems. The expectation was as follows. Given that Korean syntax requires that the two coordinated noun phrases be inflected with the parallel structure as shown in (42), speakers will inflect the two nouns using the same inflectional template if they obey this syntactic constraint. I conjecture that in sentences with two conjuncts, the first conjunct will be inflected in the preferred way appropriate to the final segment, and the second will then be constrained to match the first. In other words, speakers choose the most preferred inflectional template for the first conjunct, but the inflection of the second conjunct is determined by the inflectional template provided by the first conjunct.

[3] Informal observation of production by Korean adults suggests that this structure improves when the suffix is only on the later phrase. In that case, suffixation is interpreted as a topic marking. However, such sentences are natural only when topic marking in the second clause is supported by additional context of the discourse; without any information, the sentence with the case marking only on the second clause is as unnatural as the one in (c).

This conjecture will be born out in the current experiment. Specifically, how can this syntactic constraint allow us to elicit alternating forms of coronal obstruent-final nouns?

Suppose the first conjunct of a coordinated sentence has a noun that ends in a sonorant or a noncoronal obstruent. Those nouns will be inflected using the adult-like inflectional structure in (24), because that is the preferred way of inflecting those nouns, as we observed from the first experiment. Suppose in this coordinated sentence, the second conjunct contains a noun ending in a coronal obstruent. Child speakers in the intermediate acquisition stage want to inflect those nouns by employing deviant inflectional templates as we found from the first experiment. However, if they respect the parallelism constraint imposed on coordinated sentences, then the item in the second conjunct will also need to be inflected using the adult-like inflectional template. In this case, we predict that child speakers will produce alternating forms of coronal obstruent-final nouns as a consequence of the constraint ranking of Markedness over Input-to-output Faithfulness constraints. this inflectional template. However, such a successful behavior will be observed, only if they know how to produce alternating forms of coronal obstruent-final nouns. If they do not know how to correctly alternate coronal obstruent-final nouns, they will fail in this constrained setting, by producing erroneous alternating forms. I will show the emergence of adult-like alternating forms of coronal obstruent-final nouns, suggesting children's capability of alternation of coronal obstruent-final nouns, even though they did not produce them in a non-controlled setting, as Experiment 1.

2.1.4.1 Design

Thirty pictures from Experiment 1 were grouped into 15 pairs. Each pair contained one picture that was designed to elicit one of the sonorant-final nouns, and one picture designed to elicit one of the obstruent-final nouns. Each stimulus was expected to elicit the same morphological structure for both nouns, either as a nominative, an accusative, or a locative or directive form. As a control, 4 stimuli were added to elicit two coronal obstruent-final nouns and two sonorant-final nouns. These additional 10 noun stems were chosen from the 2,000 most frequent noun stems in written Korean from the Sejong Corpus (Kang and Kim 2004), just as I selected target nouns in designing Experiment 1. The list of pairs with their expected inflectional suffixes is given in (44).

(44) The list of stimuli

a. Obstruent-final, Sonorant-final ({OBS, SON})

1. pap-ɨl, kam-ɨl 2. ip^h-ɨl, jənphil-ɨl 3. sup^h-ə, san-e 4.pat^h-ɨl, kaŋ-ɨl

'rice, persimmon'	'leaf, pencil'	'wood, mountain'	'field, river'
5. sot^{h}-i, ibul-i	6. os-e, kabaŋ-e	7. pis-ɨl, ankjəŋ-ɨl	8. mas-i, p'aŋ-i
'pot, pillow'	'clothes, bag'	'comb, glasses'	'taste, bread'
9. s'ias-ɨl, kjul-ɨl	10. nac-e, pam-e	11. pitʃ^{h}-i, usan-i	12. k'oʃ^{h}-ɨl, p^{h}al-ɨl
'seed, orange'	'day, night'	'light, umbrella'	'flower, arm'
13. kuk-e, pal-e	14. puək^{h}-ɨl, paŋ-ɨl	15.pak'-e,an-e	
'soup, foot'	'kitchen, room'	'outside, insid	

(-i: nominative, -ɨ: accusative, -e: locative/directive)

b. Sonorant-final, Sonorant-final ({SON, SON})

1. sam-i, il-i 2. nun-e, son-e 3. aisik^{h}ɨlim-i, ərɨm-i 4. k^{h}al-ɨl, p^{h}ilthoŋ-ɨl 5. pom-e, kaɨl-e

'three, one' 'eye, hand' 'ice cream, ice' 'knife, pencil case' 'spring, fall'

c. Obstruent-final, Obstruent-final ({OBS, OBS})

1. pulpitʃ^{h}-i, nunpitʃ^{h}-i 2. k'ɨt^{h}-e, mit^{h}-e 3. hetpet^{h}-i, pulk'otʃ^{h}-i 4. kos-il, kət^{h}-ɨl

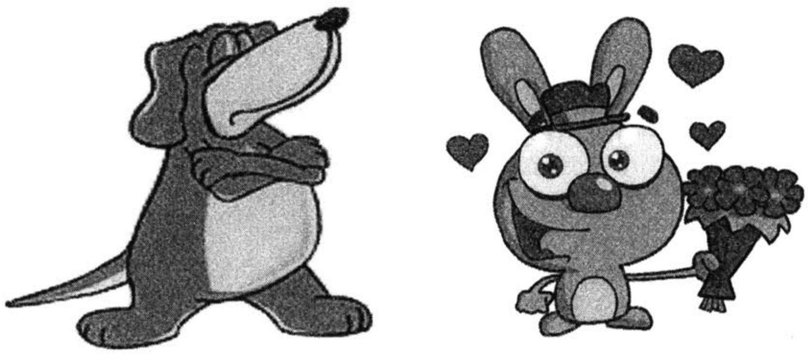
'light, eye' 'end, below' 'sunlight, firework' 'flower, out'

5. t'ɨs-ɨl, tatʃ^{h}-ɨl

'meaning, anchor'

Recall our expectation about the temporal sequencing of coordinated structures: speakers will first pick out the most preferred structure to inflect the first conjunct, and then the structure of the second conjunct will be automatically determined according to the structure provided by the first conjunct. To control for the position effect on participants' production patterns, sonorant or noncoronal obstruent nouns and coronal obstruent final nouns were paired in two different orders: 8 trials presented the picture for the sonorant-final or noncoronal obstruent final noun first, {SON, OBS}, and 7 trials presented the picture for the coronal obstruent-final noun first, {OBS, SON}. A sentence was given below each pair of pictures, in the form of a coordinated sentence, as in (45). This stimulus is an example of a pair of pictures designed to elicit a sonorant-final noun first followed by an obstruent-final noun. If participants describe pictures following our expectation, they will employ the adult-like inflectional template for the first conjunct, such as *p^{h}ar-ɨl,* 'arm-ACC, then the second noun will also be inflected using the same template. For example, an alternating form *kotʃ^{h}-ɨl* 'flower-ACC' or possibly *kod-ɨl* 'flower-ACC' will be elicited. As in Experiment 1, participants were able to choose noun stems and their inflectional patterns according to their own preference.

(45) An example of paired pictures



Kaŋadʒi-ga _______ k'o-goit-ko, t^hok'i-ga _____ til-goit-t'a.

Doggy-NOM _____ cross-PROG-and, Bunny-NOM ____ hold-PROG -DECL.

A doggy is crossing _____, and a bunny is holding _____.

2.1.4.2 Participants & Procedure

The same participants in Experiment 1 performed Experiment 2. Experiment 2 was conducted 7 months later than Experiment 1. The procedure was identical to that in Experiment 1, except that participants were not explicitly told to use formal Korean in this test because I wanted to allow them to inflect nouns in their most preferred ways including bare nouns without a suffix.

2.1.4.3 Results

All child and adult participants inflected the paired nouns with parallel structures. No instance was found in which only one of the paired nouns was suffixed or only one clause involved a nominal compound. This result tells us that Korean native speakers, regardless of their age, treat the parallelism constraint as inviolable when they create coordinated sentences. Adult participants always inflected both noun stems using the structure in (46). All nouns were suffixed with case markers, and every noun phrase involved only one noun stem, not complex noun phrases.

(46) The template of paired-nouns' inflection

Stem-{NOM[-i], ACC[-il], LOC/DAT[-e]},Stem-{NOM[-i], ACC[-il], LOC/DAT[-e]}

The same tendency was found from children in both the youngest group and the oldest group. However, children in the intermediate group did not always use this structure. They sometimes omitted suffixes in both clauses, created complex noun phrases, or selected alternative suffixes, as they did in Experiment 1. Crucially, such deviant structures were systematically observed only in their descriptions of stimuli in which a coronal obstruent-final noun was inflected in the first clause. The deviant inflectional templates elicited from this age group are presented below.

(47) The elicited forms of inflected nouns: children in the intermediate group

a. Stem-Case (NOM/ACC/LOC or DAT), Stem-Case (NOM/ACC/LOC or DAT)
b. Stem, Stem
c. [Stem-Stem]-Case(NOM/ACC/LOC or DAT), [Stem-Stem]-Suf. (NOM/ACC/LOC or DAT)
d. Stem-Case(other than NOM/ACC/LOC or DAT), Stem-Case (other than NOM/ACC/LOC or DAT)

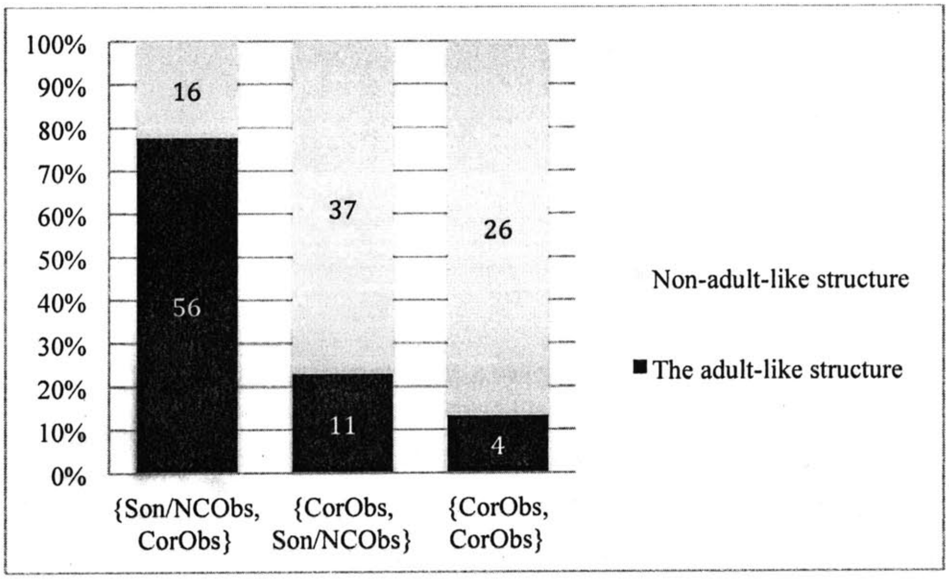
I first report the patterns of alternation observed from adults and children in the youngest and the oldest groups, who always employed the structure in (46). Because the pattern of alternations from those three groups was very similar to the results in Experiment 1, I report the results in an abbreviated fashion. Then, I show the detailed description of various inflectional structures observed from the children in the intermediate groups as in (47).

For adults, lateral-final nouns alternated with [ɾ] in prevocalic position. Underlyingly lenis /p/ and /k/ were always realized as [b] and [g] in prevocalic position; no case was found in which voiceless lenis stops /p/ and /k/ surface as [p^h] and [k^h]. Underlyingly aspirated or tensed noncoronal stops either surfaced faithfully or as their voiced lenis stop counterparts in prevocalic position (e.g., [ip^h-ɨl] ~ [ib-ɨl]). This pattern was the same as in Experiment 1. As in Experiment 1, coronal obstruent-final nouns were in variation with four coronal obstruents [s, $tʃ^h$, t^h, dʒ] in prevocalic positions, and the order of preference among variants was identical to Experiment 1: [s] was most preferred across all suffixed forms, while [$tʃ^h$] and [t^h] were the second most preferred one, and [dʒ] was least preferred.

Children in both the youngest and oldest groups always correctly alternated lateral-final nouns, as in Experiment 1. Also, the preference for voiced lenis stop [b] or [g] was stronger than its aspirated voiceless counterpart [p^h] or [k^h], as observed in Experiment 1.Children in the oldest group in most cases produced the coronal obstruent-final noun variant [s]. Children in the youngest group always inflected coronal obstruent-final nouns in [d]. This result is identical with the result in Experiment 1.

Now, let us focus on the result of children in the intermediate group, which is our main interest in the current experiment. They preferred to inflect noun stems in the adult-like inflectional template (a) of (47), but only when the noun in the first clause ended in a sonorant or a noncoronal obstruent. When the noun in the first clause ended in a coronal obstruent, children in this group preferred to employ one of the templates in (b), (c) and (d) in (47). This tendency was observed solely from this age group. The graph below shows the frequency of the adult-like inflectional structure, which refers to (a) in (47), and the total frequency of deviant inflectional structures from (b) to (d), depending on the paired nouns.

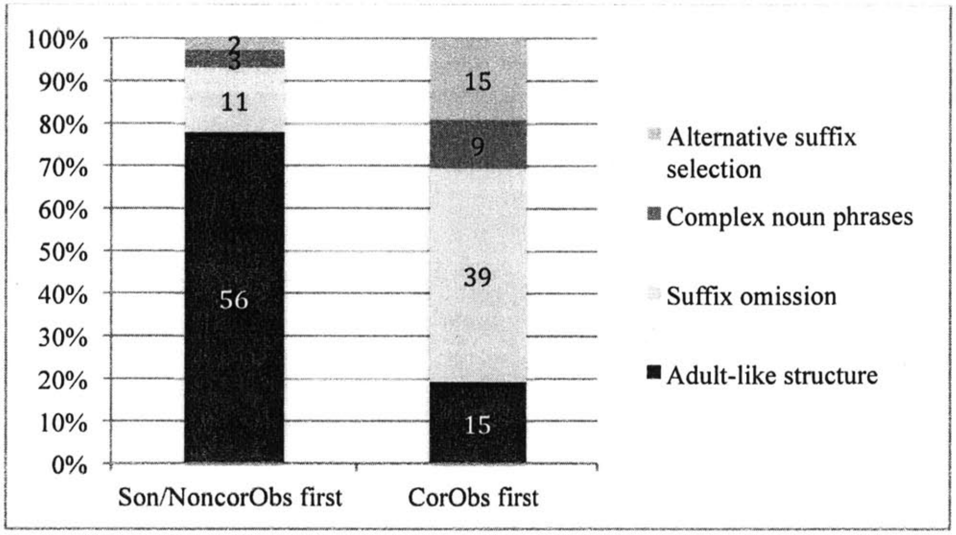
(48) The frequency of the adult template and child templates from the intermediate group



(Son: sonorant-final noun, NCObs: Noncoronal obstruent-final noun, CorObs: Coronal obstruent-final noun)

As illustrated, the frequency of the adult-like inflectional structure was higher when the first verb was either a sonorant-final or a noncoronal obstruent-final noun. Note that child participants always produced correct stem allomorphs when they used adult-like inflectional structure. The frequency of deviant inflectional structures was higher when the first verb was a coronal obstruent-final noun. The frequency of the four inflectional structure employed by children in the intermediate group depending on the stem-final segment of the first clause is shown below.

(49) The frequency of structures from children in the intermediate group



Among the deviant inflectional structures, suffix omission was most frequent. The selection of alternative suffixes was the second most preferred choice, followed by complex noun phrases. An example of each deviant structure is shown below.

(50) Examples of non-adult-like morphological structure

a. Suffix omission
sot, ibul 'pot, blanket'

b. Complex noun phrases
sod an-i, ibul sek-i 'pot inside-NOM, blanket color-NOM'

c. Alternative suffix selection
ot-hant^{h}e, kabaŋ-hant^{h}e 'clothes-LOC(ANIMATE), bag-LOC(ANIMATE)'
pat-t'o, kaŋ-to 'field-too, river-too'
nat-doŋan pam-doŋan 'day-during, night-during'

The patterns of suffix omission and noun compounding were same as in Experiment 1. As shown in (50), two more alternative suffixes were observed in Experiment 2, *–to* 'too' and *–doŋan* 'during', as well as *-hant^{h}e* 'locative' (animate). Crucially, all of the suffixes chosen by children allowed them to use the isolation form of the noun stems. For coronal obstruent-final nouns, stem-final [t] or [d] were found before those suffixes.

What we are most interested in from this experiment is how children in the intermediate group inflected coronal obstruent-final nouns when the first clause has a sonorant-final or noncoronal obstruent-final noun, and the second clause has a coronal obstruent-final noun. As illustrated in (48) and in (49), child participants were most likely to describe the first picture using the adult-like inflectional template when the noun selected to describe the first picture was sonorant-final or noncoronal obstruent-final nouns. Coronal obstruent-final nouns in the second clause of the sentence were then also inflected using the adult-like inflectional template accordingly. What we can observe here is that children in this group correctly alternated coronal obstruent-final nouns without producing any error. The elicited variant of the coronal obstruent-final noun was always [s], which is the most frequent variant of stem-final coronal obstruents in the adult language. The crucial finding is that children who avoided alternations of coronal obstruent-final nouns in Experiment 1 did alternate those items in Experiment 2 under the condition that they were not able to avoid alternations by choosing alternative morphological structures. In other words, when children had to use the adult-like inflectional structure due to the syntactic requirement, they did so, and did apply alternations.

Lexical selections were diverse both among adults and children, but neither of them shows any systematic preference either toward a sonorant-final or toward an obstruent-final noun. This is different from Experiment 1, in which alternative lexical choices were predominantly toward nouns that do not exhibit alternations or that exhibit the [l] ~ [ɾ] alternation.

The main result here is that we succeeded in eliciting suffixed forms with alternations, showing that children in the intermediate stages had the alternating form available as a second choice candidate, which emerges when the preferred repairs are ruled out by the evidently higher-ranked constraint demanding parallelism.

2.1.4.4 Discussion

The main difference between Experiment 1 and Experiment 2 was observed in the intermediate group. In Experiment 1, children in this age group employed various deviant inflectional structures, crucially predominantly when they inflected coronal obstruent-final nouns. All deviant forms involved stem-final [t] which is found in the isolation form, or [d] which alternates in voicing from the stem-final segment [t] of the isolation form. In Experiment 2, they showed the same preference to employ deviant inflectional structures when they inflected coronal obstruent-final nouns in the first clause. However not when they inflected sonorant-final nouns or noncoronal obstruent-final nouns in the first clause, this pattern was not observed. Remarkably, in this condition, since the coronal obstruent-final noun was inflected using the adult-like morphological structure, child participants in this group did correctly applied phonological alternations.

This asymmetry allows us to draw certain conclusions. First, the syntactic constraint adopted in the current study is completely undominated in Korean speakers' grammar regardless of their developmental stage: paired nouns in a coordinated sentence were inflected using the same inflectional template without exception. Second, the inflectional template of a coordinated sentence is determined by the inflection of the first verb. This tendency is consistently observed in the following experiments in section 2.2, so I will come back to this issue after presenting the next experiment.

It seems clear that producing phonologically alternating forms was children's second choice, because they did not produce alternating forms of coronal obstruent-initial nouns when they were free from the syntactic restriction: in the first clause in Experiment 2, and in a single picture description in Experiment 1. When they were free to produce inflected nouns without any restriction, they preferred various other options, all of which allowed them to avoid alternations. All of the alternatives that they employed enabled them to use the variant that is more faithful to the isolation form than the alternating adult-like forms.

The results in Experiment 2 justify my previous hypothesis: children do know that coronal obstruent-final nouns alternate, at least with [s], but prefer to avoid alternations and employ various ways, the outputs of which do not exhibit alternations found in adult language. I will provide a formal analysis of this phonological avoidance in Chapter 3.

2.1.5 Alternative analyses and their limitations

The central argument of the current chapter is that children's inflected forms over the three developmental stages are derived from the initial bias for high ranking of OO-CORR constraints. The particular way that young learners satisfy OO-CORR constraints is to inflect forms more faithfully to the isolation form, which is argued to be the base form of Korean noun paradigms (Albright 2008). Crucially, even after children figure out that nouns alternate, they have a default preference to innovative forms that satisfy OO-CORR constraints. The results of Experiment 2 confirmed that their production patterns are derived by phonological preferences, and not by ignorance of alternating adult forms.

Alternative analyses of various aspects of our data might be entertained. For example, we might suggest that unsuffixed forms were elicited because those are most frequent. This seems reasonable because in child-directed speech in Korean, the unsuffixed forms are indeed the most frequent noun form

(Kang and Kim 2004). We could also guess that the target nouns in the experiments are more frequently found inside a nominal compound rather than in a single noun form, hence children learn about the noun within a compound more predominantly than as a bare noun form. We could also imagine that an animate suffix is more familiar to children, conceivably due to its high frequency in child-directed speech in stories aimed at children. It sounds also plausible that children chose alternative items, which happen to be mostly sonorant-final ones or noncoronal obstruent-final ones. Given that sonorant-final nouns have higher type frequency in Korean nouns as shown in (41), this also seems to be a reasonable belief.

While each possibility seems plausible on its own, all such analyses fail to provide a unified account for the various child inflection patterns. More importantly, none of the analyses can provide a reason why children deviate from adults only when they inflect coronal obstruent-final nouns but not sonorant-final ones or noncoronal obstruent-final ones. Also, none of the approaches can account for why children in the intermediate stage produced the inflected forms in systematically different ways depending on the position of coronal obstruent-final nouns in a coordinated sentence. Therefore, I argue that the observed child behavior in the current study must be driven by their grammatical preference for a non-alternating paradigm that reflects the effect of highly ranked OO-CORR constraints in children's grammar.

In sum, we traced Korean children's acquisition of phonological alternations found in noun paradigms, and found experimental evidence supporting the initial OO-CORR bias. As noted, the initial OO-CORR bias has not been a main focus of work on phonological acquisition, thus the empirical work in support of the bias is rare. Therefore, it may not be wise to make a strong conclusion that child learners are equipped with the OO-CORR bias only from our observation on the acquisition of Korean noun paradigms. I extended the investigation to the acquisition of Korean verb paradigms. The previous experimental paradigms were replicated with a minor modification.

2.2 The acquisition of Korean verb paradigms

To date, phonological acquisition data on Korean verb alternations is very sparse. Kim and Philips (1988) and Lee et al. (2003) observed that young children produce verbs only in a particular vowel-initial suffixed form (-a/-ə 'imperative'), but their focus is on the stages when learners do not produce an alternating verb form. To my knowledge, it has not been investigated how Korean children comprehend or produce verbal alternations. The current section aims to figure out the patterns of alternations among children across several developmental stages. The following section lays out the patterns of alternations that children learning Korean verb paradigms need to acquire. Then I present the predictions about the patterns of alternations in early stages based on the leading hypothesis concerning the development of morphophonological grammar: the demotion of the undominated OO-CORR constraints.

2.2.1 Alternations and learning challenges

Korean has four types of verbal suffixes, vowel-initial, (-ɨ)-consonant-initial, consonant-initial, and (consonant-ɨ)-consonant initial ones, as shown in (51).

(51) Verbal inflectional suffixes in Korean

Types	Examples	RulesDistribution
V-initial	-a/-ə 'imperative'	[a] after stem-final vowel [a, o], [-ə] elsewhere
(-ɨ)C-initial	-(-ɨ)myən 'if'	'-ɨ' is present only if a stem ends in a consonant except [l][4]
C-initial	-ko 'progressive' –ta 'declarative'	No '-ɨ' insertion even after a stem-final consonant
(Cɨ)C-initial	-(sɨ)p 'addressee honorific'	(Cɨ) is present only if a stem ends in a consonant except [l]

Suffix-initial segments trigger the alternations of stem-final segments in Korean. (-ɨ)C-initial and (Cɨ)C-initial suffixes trigger the alternations of stem-final segments in the same way as V-initial and C-initial suffixes respectively; thus I consider only two types of suffixes, V-initial and C-initial ones. I further restrict the focus to the alternation of stem-final consonants. Stem-final vowels are excluded from the experimental investigation, since they show a wide range of lexically specific exceptions, whose distribution lacks synchronic phonotactic motivation. For instance, a vowel-initial suffix may trigger glide formation of a stem-final vowel, but some verbal stems resist the alternation, as (52). It would be interesting ,in the future, to explore how children acquire phonological alternations which show a wide range of variability as vowel-final verb stems in Korean. My current concern is the acquisition of stem-final consonantal alternations triggered by V-initial and C-initial verbal suffixes.

(52) A lexically specific exception to the vowel-final stems' alternation

p^hi-ə → p^hiə ~ p^hjə 'blossom' (regular) ki-ə → kiə, *kjə 'crawl' (exception)

When a child learning Korean verb paradigms detects morphemes from a word, she will try to determine their meanings. This learning task is not easy, due to a variety of phonological alternations that stem-final segments undergo. She finds that the surface realizations of a stem-final consonant may differ

[4] See Kenstowicz and Sohn (2008) for an analysis of the exceptional behavior of stem-final [l] in Korean.

before V-initial vs. C-initial suffixes. I refer to stem allomorphs before V-initial suffixes as V-stems and before C-initial suffixes as C-stems. Some distributions of V-stems and C-stems are predictable if the learner has already figured out phonotactic patterns of monomorphemic words in Korean. Examples are in (53); obstruents are voiced when V-initial suffixes follow, while they are voiceless when C-initial suffixes follow. There are two surface forms of C-stems, depending on whether sonorant-initial suffixes follow or obstruent-initial suffixes follow: the stem-final obstruent alternates with a nasal before nasal-initial suffixes. This distribution of stem allomorphs within C-stems, obstruent-final and its homorganic nasal-final stem allomorphs, is governed by the Korean phonotactic constraint of regressive nasal agreement.

(53) Phonotactically motivated alternations

V-initial suffixed forms	Obs-initial suffixed forms	Nas-initial suffixed forms
cab-a 'catch-Imperative'	cap-k'o '-Progressive'	cam-nin '-Adjectival'
tad-a 'close'	tat-k'o	tan-nin
mag-a 'block'	mak-k'o	maŋ-nin

The pattern of alternations in (54) is also predictable based on the process of coda neutralization found in monomorphemic words: all obstruents in the coda become their homorganic unreleased stop counterparts before obstruent-initial suffixes, and undergo regressive nasal agreement before nasal-initial suffixes.

(54) Phonotactically motivated alternations 2

V-initial suffixed forms	Obs-initial suffixed forms	Nas-initial suffixed forms
kap^{h}-a 'pay back'	kap-k'o	kam-nin
mat^{h}-a 'undertake'	mat-k'o	man-nin
sək'-ə 'mix'	sək-k'o	səŋ-nin
s'is-ə 'wash'	s'it-k'o	s'in-nin
is'-ə 'exist'	it-k'o	in-nin
madʒ-a 'correct'	mat-k'o	man-nin
c'otʃ^{h}-a 'chase'	c'ot-k'o	c'on-nin

V-stems ending in nasals do not alternate before C-initial suffixes as (55). V-stems ending in [ɾ] alternate to [l] before obstruent-initial suffixes and the liquid is deleted before [n]-initial suffixes as (55).

Allophonic [ɾ] ~ [l] alternation is predictable by the process of intersonorant flapping, while [ɾ] deletion ([ɾ] ~ [ ]) occurs only at certain morpheme boundaries including the boundary across a noun stem and a nominal suffix starting with [n]. Except for [ɾ] ~ [ ] alternation, a learner equipped with phonotactic knowledge is able to predict the distribution of allomorphs exhibited in the paradigms from (53) to (55).

(55) Sonorant-final verb stems

V-initial suffixed forms	Obs-initial suffixed forms	Nas-initial suffixed forms
a. kam-a 'roll'	kam-k'o	kam-nɨn
b. saɾ-a 'live'	sal-go	sal-ma, sa-nɨn

Stem-final consonants may undergo lexically restricted segmental alternations, as in (56). Some patterns of alternations are phonotactically principled: [p] and [t] before obstruent-initial suffixes in (a) and (b) in (56) undergo lenition in intervocalic position, but such patterns are not found within monomorphemic words. Some stem-final [p] alternates with [w] before V-initial suffixes, instead of undergoing voicing alternation. The contrast between [w]-final and [b]-final nouns found in prevocalic position is neutralized before obstruent-initial and nasal-initial suffixes as shown in (56). In a similar way, the contrast between lexical items involving prevocalic [ɾ], [ ] and those involving prevocalic [d] is neutralized before obstruent-initial and nasal-initial suffixes.

(56) Alternations not found within monomorphemic words

V-initial suffixed forms	Obs-initial suffixed forms	Nas-initial suffixed forms
tow-a 'help'	top-k'o	tom-nɨn
(cab-a 'catch-Imperative'	cap-k'o '-Progressive'	cam-nɨn '-Adjectival')
tiɾ-ə 'listen'	tɨt-k'o	tɨn-nɨn
i-ə 'connect'	it-k'o	in-nɨn
(tad-a 'close'	tat-k'o	tan-nɨn)

There are also alternations that are not governed by inviolable markedness constraints in Korean. Such examples are [ɾ] deletion before [n]-initial suffixes introduced in (55), and [t] deletion before V-initial suffixes in (56). Another example is in (57): stem-final [ll] in prevocalic position becomes [ɾɨ] before obstruent-initial and nasal-initial suffixes.

(57) Alternations not governed by inviolable markedness constraints

hɨll-ə 'flow' **hɨrɨ**-go **hɨrɨ**-nin

Table in (58) summarizes the patterns of stem-final consonantal alternations in Korean verb paradigms.

(58) Patterns of alternations in Korean verb paradigms

Patterns	Alternations	Phonotactics	Data
A. Phonotactically motivated Applied in monomorphemic words	[b]-V ~ [p]-Obs	Intersonorant voicing	(53)
	[p]-Obs ~ [m]-Nas	Nasal agreement	(53)(56)
	[p^h]-V ~ [p]-Obs ~ [m]-Nas	Coda neutralization Nasal agreement	(54)
	[ɾ]-V ~ [l]-Obs or -Nas except [n]	Intersonorant flapping	(55)
B. Phonotactically motivated Not applied in monomorphemic words	[w]-V ~ [p]-Obs [ɾ]-V ~ [t]-Obs		(56)
C. Not governed by markedness constraints Not applied in monomorphemic words	[ ]-V ~ [t]-Obs [ɾ]-V ~ [ ]-[n] [ll]-V ~ [ɾɨ]-Obs/-Nas		(55)(56)(57)

The patterns of alternations which are not found within monomorphemic words are likely to become the targets of reanalysis, assuming that children in the early stage of learning alternations are starting to figure out the morphology of the language. If an alternation pattern is not compelled by inviolable markedness constraints of the language, the acquisition of such pattern will be delayed more than the ones motivated by phonotactics, because we predict that learners may call on their phonotactic knowledge to understand that alternations should occur to bring the sequences into the conformity with phonotactic principles (Hayes 2004, Pater and Tessier 2006).

Another crucial factor determining the rate of constraint demotion is the availability of evidence for the rankings that need adjusting. Simply speaking, the OO-corr constraints that are violated in more alternations will be demoted faster. This learning hypothesis is a corollary of the combination of the hypothesis of the undominated status of OO-corr constraints (McCarthy 1998, Hayes 2004) with a model in which constraint rankings depend on frequencies in the data, such as Gradual Learning Algorithm (GLA; Boersma 1997, Boersma and Hayes 2001): the learner initially has undominated OO-corr constraints and ranks the constraints in a way that matches the frequencies of the learning data. In Korean verb paradigms, alternations found within monomorphemic words are more frequent than ones specific to the inflections. I will provide specific frequency information in Chapter 5. For the moment, it is sufficient to note the correlation between frequency of alternations and their availability within monomorphemic words.

The considerations on phonotactic motivation and frequency of alternations suggests that the alternations in (A) will be acquired first followed by (B) and (C) in (58).

Depending on which inflected forms are known to the learners, different types of reanalysis are possible. For instance, to<u>w</u>-a 'help' can be reanalyzed as to<u>b</u>-a, on the basis of to<u>p</u>-t'a, or in the opposite direction, to<u>p</u>-t'a may be reanalyzed as to<u>w</u>-da, on the model of to<u>w</u>-a. Albright & Kang (2008) argue that the V-initial suffixed form is the base of Korean verbal paradigms by providing the result of learning simulation in which the V-initial suffixed form of the stem emerges as the most informative cell in the paradigm -i.e. the cell which predicts the surface realizations of the other (non-base) forms with the highest probabilities (Albright 2002). Will we observe the asymmetrical reanalysis from child learners which shows the overuse of the V-initial suffixed forms, suggesting the initial OO-CORR bias?

2.2.2 The predictions of the OO-Corr bias

The OO-CORR bias hypothesis makes a prediction about the patterns of alternations along developmental stages. If the base form of Korean verbal paradigms is the V-initial suffixed form (Albright & Kang 2008), and if the constraints that require inflected surface forms to remain faithful to the base form are undominated in child grammar (McCarthy 1997; Hayes 2004), then children will initially inflect verbs so that the stem allomorphs are faithful to the V-initial suffixed form in the paradigm. In this way, OO-Corr constraints are satisfied and children construct a non-alternating paradigm. Examples of hypothetical patterns of reanalysis at the initial state are in (59). I mark ★ indicating innovative forms. Hypothetical innovative forms involve a vowel -ɨ- between the morpheme boundaries, assuming that children would repair phonotactically illegal consonant sequences by inserting a vowel, but the specific modes of repair are not crucial at this point.

(59) Hypothetical patterns of reanalysis at the initial state

a. cab-a cap-k'o → ★cab-ɨ-go 'catch'

b. tow-a top-k'o → ★ tow-ɨ-go 'help'

Child learners will then allow alternations which are found with monomorphemic words and at the same time frequent as well. At the same stage, they may not master the alternations which are newly found across morpheme boundaries and less frequent. For those cases, leveling will extend the root allomorph found in the base, as presented below.

(60) Hypothetical patterns of reanalysis at the intermediate stages

a. saɾ-a sa-nɨn →★saɾ-ɨ-nɨn

b. tow-a top-k'o →★tow-ɨ-go

c. tɨɾ-ə tɨt-k'o →★tɨɾ-ɨ-go

d. i-ə it-k'o →★i-go

e. hɨll-ə hiɾɨ-go →★hɨll-ɨ-go

This hypothesis is borne out by the experimental results of young children in the current study. Children in earlier learning stages level some verbal paradigms as predicted in (60). However, the results show that children in later stages achieve paradigm uniformity in different ways. I present evidence that children in later stages show a conspiracy of repairs, in order to produce non-alternating paradigms. These involve various strategies, not necessarily limited to phonological repairs: children produce morphologically extended formations, or they make unexpected lexical choices. Both of these deviations from adult usage occur in children's productions only when needed to avoid certain harder-to-learn alternations. For this reason, I identify such patterns as repair strategies. I further present data showing that children prefer to repair forms, even with complete knowledge of the adult forms. The argument will be that the production of alternating forms is blocked among children, due to OO-CORR constraints, which are given high ranking in children's grammar.

2.2.3 A production experiment 3

A major goal of the experiment is to observe patterns of verbal inflections along the various developmental stages before children have completely mastered the phonological alternations. My literature search has not found any evidence as to when young Korean learners have mastered control of the verbal alternations. A report observing native-Korean children under 36 months shows that 36-

months-old infants do not produce alternating verbal forms at all (Lee et al. 2003). Personal experience suggests that Korean children around 48 months of age still do not productively attempt alternating verbal forms and children around age seven produce various alternating forms, but the patterns of their alternations still deviate from the adult forms. Based on these observations, I investigate the acquisition of Korean verbal inflections by children in the age range from four to seven (4;1-7;8).

2.2.3.1 Design

To elicit the inflected forms of verbs, I used a picture description task. Pictures were shown to participants, and a sentence was given for each picture, which was missing a verb. Since the goal was to elicit verbs, other sentence components, such as a subject, an object or an adverb, were given by the experimenter, as in (61).

(61) An example of the picture description task

Namca-ga himc^{h}a-ge ______.

he Man-Nom joyful-adv _______.

A man ____ joyfully.

Participants were asked to describe the pictures, without any additional restrictions. The expectation was that they would select the verbal root that they think most proper to describe the depicted picture. For instance, one may describe the depicted picture (61) as *a man is walking*, *a man is moving*, or possibly *a man is smiling* depending on one's interpretation. Participants would also use the most preferred inflectional pattern for the verbal root, such as progressive, declarative, etc. The possible templates of inflected forms of verbs in Korean are presented in (62). The templates are provided, assuming that the most natural way of describing a picture is in a present tense declarative form.

(62) Inflected forms of verbs in a present tense declarative form in adult Korean

a. Cstem-PRES/PRESPROG-DECL
b. Vstem -CONJ-{Deictic, Epistemic, Directional ...}-PRES/PRESPROG-DECL
c. Vstem -CONJ-Cstem-PRES/PRESPROG-DECL
d. Vstem -CONJ-Vstem-CONJ-{Deictic, Epistemic, Directional ...}-PRES/PRESPROG-DECL

Verbal roots cannot stand alone in Korean. A verbal root directly followed by a declarative marker is not used in Korean. A tense morpheme or an aspectual morpheme should be specified before a declarative marker. Thus, the morphologically shortest verbal inflection forms in Korean are the forms in (a). Tense morphemes and aspectual morphemes directly follow the verbal root as shown in (a) above. The correct form of the verbal stem allomorph selected by a present tense morpheme and a present progressive morpheme is the Cstem. A mood morpheme follows the present tense morpheme or the present progressive morpheme. A verbal root can be suffixed with extra morphemes as in (b), such as a deictic, an epistemic, or a directional morpheme before the tense morpheme or the aspectual morpheme. In this longer template, the conjunctive morpheme is needed between the verbal stem and the extra morpheme. The correct stem allomorph given a conjunctive morpheme is the Vstem. A tense morpheme or an aspectual morpheme directly follows extra morphemes {Deictic, Epistemic, Directional ...}, and then the mood morpheme is suffixed. A verbal root may take another verbal root to construct a serial verb construction as in (c). A conjunctive morpheme is required between the two verbal roots, and the correct stem allomorphs before a conjunctive morpheme is the Vstem. After the two verbal stems are conjugated, a tense morpheme or an aspectual morpheme is suffixed, followed by a mood morpheme. A more complex inflection is also possible as in (d), which basically involves the serial verb construction in (c) as well as the extra morphemes in (b). Examples of adult inflected forms of the verb *kər-* 'walk' are given in (63).

(63) Adult inflected forms of a verb *kər-* 'walk'

a. kən-nin-da	walk-Pres-Decl	'walks'
kət-k'oit-t'a	walk-PresProg-Decl	'is walking'
b. kər-ə-ga-n-da	walk -Conj-Deictic-Pres-Decl	'walks away (from the speaker)'
kər-ə-ga-goit-t'a	walk-Conj-Deictic-PresProg-Decl	'is walking away'
c. kər-ə-ori-n-da	walk -CONJ-ascend-PRES -DECL	'ascend by walking'
kər-ə-ori-goit-t'a	walk -Conj-ascend-PresProg-Decl	'is ascending by walking'

d. kəɾ-ə-oll-a-o-n-da	walk-Conj-ascend-Conj-Deictic-Pres - Decl	'ascend by walking toward (the speaker)'
kəɾ-ə-oll-a-o-goit-t'a	walk-Conj-ascend-Conj-Deictic-PresProg-Decl	'is ascending by walking toward'

Recall that the base form of Korean verb paradigms is hypothesized to be the V-initial suffixed form. As shown in the table above, morphologically shortest forms in (a) use the stem allomorph –e.g., *kən-* or *kət-*, different from that of the base form, *kəɾ-*, while longer forms from (b) to (d) use the stem form found in the base form. Therefore short forms violate OO-Corr correspondence constraints, while complex forms do not.

Participants were shown thirty-one stimuli presenting a picture and a sentence, as in (61). Each picture was designed to elicit a single inflected verb. The expectation was to elicit the inflected forms of thirty-one verbs, in which various types of alternations can be observed. The verbs I expected to elicit were selected from the full set of Korean verbs whose stem ends in a consonant, based on the following criteria; (a) the token frequency of the verb should be at least 1,000 (Median =3,501), so that verbs would be familiar to young learners, and (b) the verbs express either motions (e.g., walk, fly, dance) or the state of an object (e.g., round, blue, long) so that the meaning of the verb can be clearly presented by a picture. Due to these restrictions, not all types of alternations found in Korean verbal paradigms were included. For instance, no verb which presents an alternation of a consonant cluster to a single consonant was included (e.g., [lp] ~ [l]), because such verbs do not have token frequencies over 1,000. Also no verb exhibiting the alternation between a glottalized obstruent and its homorganic lenis stop was presented (e.g., [k'] ~ [k]), because the meanings of the verbs involving such alternation are not easy to represent by a picture. As a result, thirty-one verbs involving nine types of segmental alternations were selected as in (64). 'Types' in (64) indicate the alternations of the stem-final segment before V-initial, obstruent-initial and sonorant-initial suffixes. Individual verbs are presented in V-initial suffixed forms.

(64) Selected verbs and their alternation type

Types	Frequency	Verbs
b~p~m	3	cab-a 'catch', ib-ə 'put on', cəb-ə 'fold'
d~t~n	1	tad-a 'close'
g~k~ŋ	4	məg-ə 'eat', cəg-ə 'write', mag-a 'block' nog-a 'melt'
p^h~p~m	3	kiph-ə 'deep', ciph-ə 'hit', noph-a 'high'
ll~ɾi~ɾɨ	5	hɨll-ə 'flow', pull-ə 'call', oll-a 'climb', call-a 'cut', mall-a'thin'
ɾ ~l~Ø	4	yəɾ-ə 'open', miɾ-ə 'push', uɾ-ə 'cry', kiɾ-ə 'long'
w~p~m	3	cuw-ə 'pick up', tow-a 'help', kuw-ə 'bake, roast'
ɾ~ t~n	4	kəɾ-ə 'walk', tiɾ-ə 'listen to', muɾ-ə 'ask', siɾ-ə 'load'
s~t~n	3	pəs-ə 'take off', s'is-ə 'wash', pis-ə 'comb'
Total	31	

Pictures were designed to elicit the inflected forms of the target verbs in (64). I chose pictures either from Google images with permission, or if necessary, they were created as colored illustrations especially for this experiment by a graduate student at the MIT Media Lab. I first took 76 pictures and asked three adults, who did not participate in the experiment, to describe the pictures in a written form. Among the 76 pictures, I selected 31 that all three adults described using the same verbal-stems, and those were used in the experiment.

2.2.3.2 Procedure

A web-based experiment was conducted. The procedure was same as that of Experiment 1. The parents of the child participants were asked to help their children access the experiment. Each participant accessed the experiment individually, and no time limit was imposed to complete the test. Adults were asked to type their answers directly on the answer sheet shown on the screen. Children were asked to give their answers orally and their parents typed the children's answers on the sheet, to avoid the possibility that children might not be able to write their answers, due to their insufficient knowledge of the Korean spelling system. Once an answer was typed, participants were guided to the next question. I asked the parents not to give their children response-contingent feedback. They were also asked to write down their child's answers without correcting any errors. Since the Korean spelling system does not reflect phonetically predictable alternations such as intervocalic voicing or nasal assimilation, and thus the answer transcribed by the parents may not show whether children correctly applied such alternations, answers were also recorded during the test using the internal microphone of each participant's computer.

Before the test session, participants were given three examples, to allow them to get acquainted with the form of the test. The three examples all showed vowel-final verbs, so that participants were not shown any instance of stem-final consonants' alternations before the test. All participants were asked to complete the full set of an experiment in a single session.

2.2.3.3 Participants

Eleven native Korean children aged 4;1-7;8 participated in the experiment, along with eight adult native Korean speakers for purposes of comparison. All children study in regular kindergartens in Seoul and all adult participants were standard Seoul Korean speakers. Since sentences were presented in written form, child participants were chosen from those who have good knowledge of the Korean writing system.

2.2.3.4 Results

To preview the results, children preferred to inflect verbs so that they could construct non-alternating paradigms, supporting the OO-CORR bias. The three following subsections report different types of deviations elicited from children, all of which better satisfy OO-CORR constraints than the corresponding adult forms do. The way children achieved paradigm uniformity was by inflecting verb forms more faithfully to the base form of the paradigm compared to adult forms. This tendency of verbal inflection was found more frequently when they inflected verbal forms involving lower frequency alternations.

Except for two answers from a single participant, adults always inflected verbs in one of the two inflectional patterns: a verbal stem followed by the present tense followed by the declarative morpheme as (65)a, or a verbal stem followed by the present progressive morpheme followed by the declarative morpheme as (65)b. As mentioned, these two forms are the morphologically simplest verbal inflections in Korean.

(65) The observed templates of verbal inflections from adults

a. Stem- Pres-Decl

b. Stem- PresProg-Decl

An example of adults' inflection of the verbal stem *kət-* 'walk' is shown below. In those adult-like inflectional templates, the correct Cstem was always selected by adult participants. For example, adults properly used the stem allomorph *kən-* before a present suffix *-nin-*, and the stem allomorphs are *kət-* or *kək-* before the present progressive suffix *-koit-*.

(66) Inflectional patterns from adult participants for kət- 'walk'

a. Cstem- Pres-Decl

kən-nin-ta 'walk-Pres-Decl'

b. Cstem-PresProg-Mood

kət/kək-koit-ta[5] 'walk-PresProg-Decl'

Children also used the adult-like inflectional templates in (66), but in some cases their verbal inflections deviated from adult forms as well. Mainly three types of deviations were observed from children. First, incorrect stem allomorphs were found in which children used the adult-like inflectional templates in (66), but they chose the wrong stem allomorph, given the suffix. Second, morphologically extended forms were found, in which they inserted extra morphemes in verbal inflection. Third, alternative lexical choices were observed, in which children selected different verbal roots from adults. For example, a picture that all adult participants described using the verbal root *kər-* 'walk' was described by children using *ka-* 'go', *umcigi-* 'move' or *t'am hilli-* 'sweat'. Table (67) shows the three types of children's deviations from adults with examples.

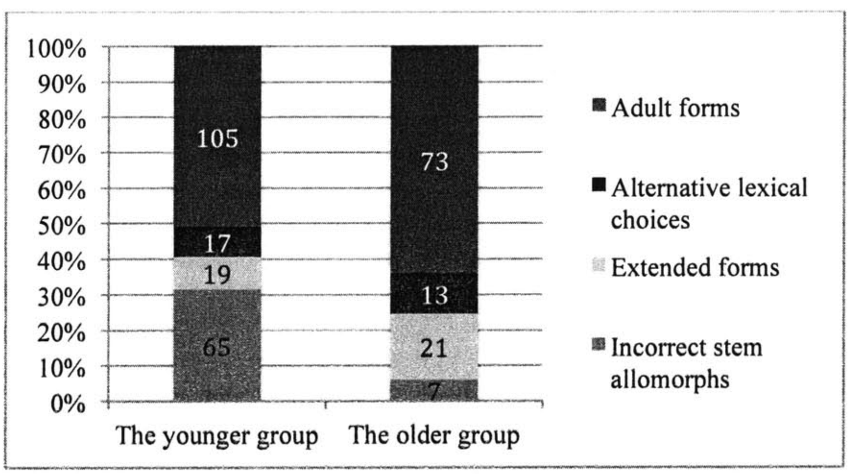
[5] In some participants' answers, regressive place assimilation was applied from a suffix-initial velar to a stem-final coronal obstruent, which is an optional process in Korean.

(67) Types of children's deviations from adults

Terms	Definitions	Examples
Incorrect stem allomorphs	Vstem before Csuffix	kər-ɨ-nɨn-da[6] (Correct form: kən-nɨn-da)
Extended forms	Verbal forms as in (b), (c) or (d) in (62).	kər-ə-ga-n-da 'Vstem-Conj-Deictic-Pres-Decl' kər-ə-dɨrəga-n-da 'Vstem-Conj-enter-Pres-Decl'
Alternative lexical choices	Different choices of verbal roots from adults	ka- 'go'-, umdʒik- 'move'-, or t'amhɨlli- 'sweat'-, instead of kər- 'walk'-.

The distribution of incorrect stem allomorphs and extended forms was different depending on the age of the participant. The frequency of alternative lexical choices was not significantly different. I classify child participants into two age groups with respect to the major pattern of the deviant forms between incorrect stem allomorphs and extended forms. Children in the younger group involve 7 children aged 4;1-5;3: M=4;9, who all produced incorrect stem allomorphs more frequently than extended forms. Children in the older group involve 4 children aged 5;1-7;8: M=6;2, who used morphologically extended forms more than incorrect stem allomorphs. Adult forms were produced more from children in the older group. The graphs in (68) show the distribution of incorrect stem allomorphs, extended forms, alternative lexical choices, and adult forms in each child group.

(68) The frequency of verbal inflection forms in two child groups



[6] The example form 'kər-ɨ-nɨn-da' involves the inserted vowel '-ɨ-', which otherwise would have created a phonotactically illegal sequence [ɾn] in Korean. Child participants always inserted a vowel at the morpheme boundaries exhibiting phonotactically illegal sequences, which shows their knowledge of phonotactics. The types of inserted vowels were not systematic, and the question on what conditioned the quality of inserted vowels is not investigated here.

Wrong forms always involved the incorrect stem allomorph, given the suffix. For instance, a child wrongly selected the stem allomorph *cuw-* 'pick up' instead of the correct *cum-*, before the nasal-initial suffix *–nɨn*; or a child selected the stem allomorph *kər-* 'walk' instead of *kət-*, before the obstruent-initial suffix *-koit*. Crucially, the selection of the stem allomorphs was systematically asymmetrical: children incorrectly chose a Vstem where a Cstem is required, but no case was found in which they used a Cstem where a Vstem is needed. Some of the innovated forms employing Vstems created the potential for violating phonotactic legality in Korean, because they involved illegal consonantal sequences such as [w-d], [w-n], [ɾ-d], [ɾ-n], [s-d] and [s-n]. Children always inserted a vowel between a Vstem and the following affix, when the sequence would otherwise have been illegal. This tendency shows younger children's good knowledge of Korean phonotactics. The quality of the inserted vowels was not systematic, as shown in (69)[7].

(69)

Adult forms		Forms involving incorrect stem allomorphs	V-stems
a. **cum**-nɨn-da	'pick up-PRES-DECL'	**cuw**-u-n-da 'pick up-u-Pres-Decl'	**cuw-**
b. **kət**-koit-da	'walk-PRESPROG-DECL'	**kər**-ɨ-goit-da 'walk-ɨ-Prog-Decl'	**kər-**
c. **s'in**-nɨn-da	'wash-PRESPRES-DECL'	**s'is**-ə-n-da 'wash-ə-Pres-Decl'	**s'is-**

Incorrect stem allomorphs were found only from a subset of the verbs, and such verbs involve specific patterns of alternations: ll ~ɾɨ, ɾ ~Ø, w~p, w~m, ɾ~t, ɾ~n, s~t and s~n alternations. No verb was elicited in an incorrect form if the verbal paradigm involves voicing alternation (b~p, d~t, g~k), nasal alternation (b~m, d~n, g~ŋ, p^h~m), lateral alternation (l ~ɾ), or coda neutralization (p^h~p, p^h~m). The table below shows the frequency of the alternations found in verbs inflected with incorrect stem allomorphs.

(70)

	Younger children (N=7)	Older children (N=4)
b~p, d~t, g~k	0/33	0/20
b~m, d~n, g~ŋ	0/21	0/12
p^h~p	0/7	0/4
p^h~m	0/14	0/8
ɾ~l	0/13	0/8

[7] The inserted vowels always showed rounding harmony with the preceding vowel in the stem. It would be worth investigating why children inserted a vowel that satisfies rounding harmony with the preceding vowel when they repair phonotactically illegal sequences.

ɾ~Ø	9/12	0/7
ll~ɾɨ	13/29	2/20
w~p	3/6	1/3
w~m	9/10	1/6
ɾ~t	8/11	1/4
ɾ~n	10/12	1/7
s~t	5/7	1/2
s~n	8/14	0/7

The specific proportion of incorrect stem allomorphs is different in different age groups, but the types of alternations which were found from incorrectly inflected verbs were same between the two age groups.

Some of the children's responses included morphologically extended forms. I identify morphologically extended forms as those involving the morphemes that adult participants rarely incorporated into the verbal inflection in the current experiment. As illustrated in (71), children employed morphemes in verbal inflections by specifying the direction of a motion from the perspective of the speaker as (71)a, by creating a serial verb construction as (71)b, or by inserting an epistemic morpheme such as look or seem as (71)c. Extra morphemes in extended forms are underlined in (71).

(71) Adult forms	Extended forms
a. kən-nɨn-da	kəɾ-ə-o-n-da
'walk-Pres-Decl	'walk-CONJ-DEICTIC-PRES-DECL'(walk toward a speaker)
b. məŋ-nɨn-da	məg-ə-pəɾi-n-da
'eat-Pres-Decl'	'eat-CONJ-clean-PRES-DECL' (eat up)
c. cak-t'a	cag-a-boi-n-da
'small-Decl'	'small-CONJ-look-PRES-DECL' (looks small)

As introduced in (62), morphologically extended forms require the conjunctive morpheme –a/-ə, in order to accommodate the extra morphemes into the verbal inflection, as in (71). Given the conjunctive morpheme –a/-ə, a V-initial suffix, the correct stem allomorphs in extended forms are Vstems. Children properly produced Vstems without exception when they created morphologically complex forms using a conjunctive morpheme.

As with the tendency found for verbs involving incorrect stem allomorphs, extended forms were observed in the restricted set of the verbs as well, which involve specific types of alternations. The types of alternations involved in these forms are very similar to the ones found in forms with incorrect stem allomorphs. The table below shows the frequency of alternations in verbs inflected in extended forms.

(72) The frequency of alternations in verbs inflected in extended forms

	Younger children (N=7)	Older children (N=4)
b~p, d~t, g~k	0/33	0/20
b~m, d~n, g~ŋ	0/21	0/12
p^h~p	0/7	0/4
p^h~m	0/14	0/8
ɾ~l	0/13	0/8
ɾ~Ø	2/12	0/7
ll~ɾɨ	6/29	5/20
w~p	2/6	2/3
w~m	1/10	4/6
ɾ~t	3/11	2/4
ɾ~n	1/12	4/7
s~t	2/7	0/2
s~n	2/14	4/7

Despite differences in the proportions of each segmental alternation, the types of alternations are similar to those in table (70). None of the verbs subject to the voicing alternation, the nasal alternation, the lateral alternation, and coda neutralization were elicited as extended forms.

The choices of the verbal items vary, due to the design of the experiment: participants were able to choose the verb roots. Adult also made alternative lexical choices in 15 out of the total number of adults' answers 248 (6%). Alternative lexical choices from adults all cluster together: they describe motion events by a neutral motion verbal stem *ga* 'go', instead of a specific manner verbal stem such as 'walk', 'climb', or 'run'. For children, the patterns of alternative lexical choices were more diverse. Verbal roots that were expected but not chosen by children involved specific patterns of alternations. This is a similar tendency as found in the verbs inflected with incorrect stem allomorphs and the ones inflected in extended forms, even though the patterns of alternations in this case are less systematic than in the other two forms. The frequency of alternations found in verbs that children avoided is given in Table (73).

(73) The frequency of alternations in verbs that children did not select

	Younger children (N=7)	Older children (N=4)
b~p, d~t, g~k	2/35	0/20
b~m, d~n, g~ŋ	0/21	0/12
p^h~p	0/7	1/4
p^h~m	0/14	0/8
ɾ~l	1/14	1/8
ɾ~Ø	1/14	0/8
ll~ɾɨ	3/35	0/20

w~p	1/7	1/4
w~m	4/14	2/8
ɾ~t	3/14	4/8
ɾ~n	2/14	1/8
s~t	0/7	2/4
s~n	0/14	1/8

The verbal stems that were not chosen by children involve the alternations children inflect with incorrect stem allomorphs and in extended forms. Children instead chose other lexical items, which were different from the target ones. In most cases, the alternative lexical choices were still plausible interpretations of the given pictures. For instance, they described a picture from which the expected description was the river flows fast, as the river moves fast; a man is taking off his pants as a man pulls his pants downward. Sometimes the selected items were ungrammatical in a given sentence: they chose an intransitive verb where an object was given in a sentence, such as a girl combs her hair as a girl is small her hair (intended meaning: a girl's head is small), or they chose a verbal item that is unnatural with a given adverb, such as a girl helps an old lady delightedly as a girl likes an old lady delightedly. The ungrammatical sentences comprise less than 2% of the total of children's answers.

Children most frequently chose lexical items that do not exhibit any alternation at all in their surface forms, or some items that involve voicing and nasality alternations. The table below illustrates the types of alternation and their proportions among alternatively selected verbal roots in each age group.

(74) The frequency of alternations in non-target verbs chosen by children

	Younger children (N=7)	Older children (N=4)
no alternation	9	5
b~m, d~n, g~ŋ	2	1
b~m, d~n, g~ŋ	4	3
p^h~p	0	0
p^h~m	0	0
ɾ~l	3	1
ɾ~Ø	0	1
ll~ɾɨ	1	0
w~p	1	0
w~m	0	0
ɾ~t	1	1
ɾ~n	0	0
s~t	1	0
s~n	0	1
Total	23	13

The observed patterns of children's deviations from adults in inflecting verbs are summarized in (75).

(75) Summary of children's deviations

a. Both younger and older children inflected verbs in different ways from adults, but specifically when the verbs exhibit some specific alternations (e.g., [w] ~ [p]).

b. Younger children incorrectly chose a V-stem where a C-stem is required. Older children created extended forms using a V-stems.

c. From both younger and older children, alternative verbal roots were selected, and the roots were selected from the paradigms that do not exhibit alternations or from paradigms that exhibit the patterns of alternations that children reliably produced (e.g., [b] ~ [p]).

2.2.3.5 Discussion

Children in both the younger and older groups used the adult-like inflectional templates, Stem-PRES/PRESPROGRESS-DECL. This fact indicates that children in both age groups do know the adult template of verbal inflection. Children in the younger group inflected verbs using incorrect stem allomorphs for 33% of their verbal inflections (73 out of 217), suggesting that they have not yet fully acquired the forms of the verbal stems before a present tense morpheme or a present progressive morpheme. Crucially, systematically the Vstem, the stem allomorph found in the base form of the paradigms, was selected instead of the Cstem. Children in the older group correctly used the Cstem when they employed the adult template of verbal inflection: 11% of their verbal inflections (14 out 124) involve the incorrect stem allomorph. This result shows that children in the older group are able to inflect verbs in the correct adult forms.

Despite their good knowledge of the adult morphological structure, children in the older group deviated from adults in inflecting some verbs by employing morphologically extended forms, or by choosing alternative lexical items, all of which allowed them to inflect verbs using the Vstem, the stem allomorph identical to the base form. In other words, children do seem to know how to inflect verbs in the adult forms, but they have a tendency to not attempt verbal inflection in the adult forms, which would otherwise cause some specific alternations. Instead, they repaired verbal forms at morphological or at lexical levels.

In order to assure that the children's inflection patterns observed in Experiment 3 is driven by their preference to avoid specific alternations, I conducted Experiment 4. The idea is as follows: in a controlled condition in which children are prevented from employing child forms, they will inflect verbs in adult forms. The results of Experiment 4 show that the children successfully employ correct adult alternations, which confirms that their inflected forms observed in Experiment 3 are indeed motivated by their phonological preference to inflect verbs without causing some alternations, not by their ignorance of the correct adult forms.

With the confirming evidence in support of the claim, I will then consider why some verbs are inflected in different ways from adult forms while others are not, across both age groups. The argument will be that such verbs involve alternations that violate highly ranked OO-CORR constraints. This supports the claim that he demotion of some OO-CORR constraints are complete in the intermediate stages, while other OO-CORR constraints are still in the process of demotion to their correct lower ranking. Before they have been demoted, children attempt to inflect verbs in ways that the stem remains identical to the base form, as required by OO-CORR constraints: incorrect stem allomorphs from younger children and extended forms from older children.

2.2.4 A production experiment 4

I designed a controlled setting in which participants can be constrained to use adult forms. In order to impose this restriction, I employed a syntactic structure that should restrict participants' inflection patterns. The specific restriction was structural parallelism found in Korean coordinated sentences, just like the one employed in testing the acquisition of Korean noun inflections. Korean syntax requires that two verbs in a coordinated sentence be inflected in morphologically parallel structures. For instance, if a clause in a coordinated structure is inflected without deictic, epistemic, directional suffix or additional verbal root, the other clause should also be inflected without an extra morpheme, as shown in (76). If a clause in a coordinated structure is inflected with these additional morphemes, the other clause should also involve parallel morphemes, as in (76). Since it is a structural requirement, the specific meaning of the extra morphemes in different clauses may differ. For example, it is grammatical if the first clause contains a deictic suffix –ga 'away', and the other clause involves a deictic suffix –o 'toward', so long as the deictic suffixes appear in both clauses. However, if only one of the clauses involve extra morphemes, the coordinated sentence is unnatural marked as * in (76). A present tense morpheme[8], a present

[8] The past tense marker in Korean coordinated sentences is ambiguous (Cho 1995); a null tense in the first clause of a coordinated sentence may be interpreted as present or as past when there is a past tense morpheme in the final clause. I expected that the natural interpretation of a given picture is present, thus a present tense is always marked on the final clause, the current setting assumed that the tense is marked only in the final clause.

progressive morpheme and a mood morpheme are suffixed only at the final clause of a coordinated sentence. (Chung 2005, Yoon 1997).

(76) Legal structures of a Korean coordinated sentence

a. Stem-Connective, Stem-PRES/PRESENTPROGRESIVE-MOOD.
b. Stem-DEICTIC-Connective, Stem-DEICTIC-PRES/PRESENTPROGRESIVE-MOOD.
c. * Stem-DEICTIC-Connective, STEM-PRES/PRESENTPROGRESIVE-MOOD.

Examples of grammatical coordinated sentences in Korean are given in (77). The parallel parts are in squared brackets in the examples below.

(77) Deictic suffixes in both clauses (a) or in neither of the clauses (b)

a. John-i kere-ga-go, Mary-ka tallie-o-n-da
John-nom [walk-away]-and, Mary-nom [run-toward]-pres-decl
b. John-i orɨ-go, Mary-ka kən-nɨn-da
John-nom [run]-and, Mary-nom [walk]-pres-decl

In order to employ the structural restriction imposed on Korean coordinated sentences, I designed Experiment 2 as a paired-picture description test. The expectation was as follows. If participants know the syntactic constraint imposed on a coordinated sentence, and if the constraint is undominated, they must employ the adult choice in one clause when another verb in a coordinated sentence constrains the template of verbal inflection. Recall that children almost always inflected some verbs as in adult forms in Experiment 1. Assuming that they continue to inflect such verbs using adult-like morphological structure in Experiment 2, I expected that the adult forms of such verbs could impose the structural restriction on the other verb in a coordinated sentence, which was originally inflected in non-adult form in Experiment 1.

2.2.4.1 Design, Procedure, & Participants

In each trial, participants were shown two pictures and asked to describe the two in a sentence. I expected that they would use a connective morpheme such as *–ko* 'and', *-ciman* 'but', *-nɨnde* or *-nɨnbanmyən* 'on the contrary' at the end of the inflection of the first verb to indicate the coordination of the two clauses.

As in Experiment 3, only the verbs were elicited, and other sentence components such as a subject, an object or an adverb were given in the sentence by the experimenter.

The target verbs were same as in Experiment 3. Since the goal of Experiment 4 was to elicit two verbs from a pair of pictures, the target verbs were paired according to the following criteria. First, a verb that children preferred to inflect in adult form in Experiment 3 was paired with a verb they preferred to inflect in child form. Second, a transitive verb that requires an object as a sentence component was paired with another transitive verb, and an intransitive verb was paired with another intransitive verb, so that the syntactic structure, of the two clauses could be similar.

Due to restrictions of the design, some pictures were not paired, primarily because the number of verbs that children preferred to inflect in adult form and in child form was not identical. I paired the remaining pictures together, which served as controls for the experiment. For instance, a picture expected to elicit *kip^{h}ə* 'high' was paired with a picture expected to elicit *nop^{h}a* 'deep', both of which were preferred to be inflected in one of the child forms in Experiment 1. Because the thirty-one verbs from Experiment 1 is an odd number, an additional verb *t'uij-ə* 'run' was added for the purpose of pairing, and it was paired with the verb *kəɾ-ə* 'walk'. The list of the pairs is presented below.

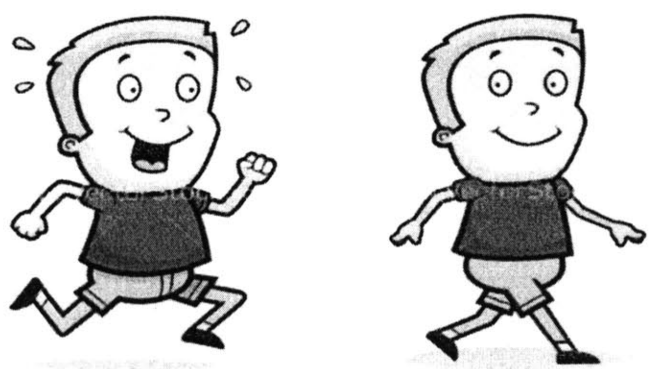
(78) The list of pairs children inflected in an adult form and in a deviant form

cab-a 'catch'	s'is-ə 'wash'
ib-ə 'put on'	pəs-ə 'take off'
cəb-ə 'fold'	tiɾ-ə 'listen to'
ta-da 'close'	siɾ-ə 'load'
yəɾ-ə 'open'	pull-ə 'call'
cəg-ə 'write'	call-a 'cut'
mag-a 'block'	oll-a 'climb'
nog-a 'melt'	hɨll-ə 'flow'
ciph-ə 'put'	cuw-ə 'pick up'
məg-ə 'eat'	kuw-ə 'bake, roast'
miɾ-ə 'push'	pis-ə 'comb'
uɾ-ə 'cry'	tow-a 'help'
kiɾ-ə 'long'	mall-a 'thin'
t'ju-ə 'run' (Added)	kəɾ-ə 'walk'

The list of pairs children inflected in an adult form	
kiph-ə 'deep'	noph-a 'high'
cab-a 'catch'	miɾ-ə 'push'
tad-a 'close'	yəɾ-ə 'open'
The list of pairs children inflected in a child form	
oll-a 'climb'	kəɾ-ə 'walk'
kuw-ə 'bake, roast'	call-a 'cut'

In order to control the position effects of the clauses, every stimulus was presented twice in two different orders: once a picture to elicit a verb that children preferred to inflect in adult form in Experiment 1 was given first, and another time a picture to elicit a verb that children preferred to inflect in child form was presented first. For example, the pair of pictures in (79) was presented twice, first with the walking picture followed by the running picture, and another time in the opposite order. Pairs of pictures were randomly ordered, and no pairs with the opposite order of the two pictures were presented in a row.

(79) An example of the paired pictures description task



yen-c'ok ai-ga p'al-li ___________, orən-c'ok ai-ga chunchun-he_______.
Left-side boy-nom fast-adj ________, right-side boy-nom slow-adj____.
A child on the left ________ fast, a child on the right __________ slowly.

The same three adults who helped design and select the pictures in Experiment 1 also participated in confirming the properness of the pairing of the pictures for the current experiment.

The procedure of the test was identical as Experiment 1: adults were asked to type their answers and children were asked to give their answers orally and their parents wrote them down. All of the answers were also recorded. As in Experiment 1, participants were able to choose a verbal roots and its inflectional pattern of their own choice. For instance in (79), they were expected to use the target verbal roots run and walk, but other possible descriptions such as is sweating or smiles were possible. The same participants from Experiment 1 completed Experiment 2.

2.2.4.2 Results

Among older children, the structures of certain verbal inflections differ according to the position of the verb in the sentence (e.g., the inflection patterns of a verb *kər-* 'walk' in Type 1 vs. Type 2). This positional effect on the inflectional templates was not observed in adults and in younger children. Younger children produced forms involving incorrect allomorphs when inflecting some verbs, but they always employed the same inflectional templates regardless of a verb's position in a sentence. The examples below show the robust inflectional pattern among adults and younger children regardless of the position of the verb in the sentence, and the distinctive inflectional patterns elicited from older children, according to the position of the verb.

(80) The position effect on the inflectional pattern of a verb

a. Type 1
Adults, younger children, and older children: stem-Conj, stem-Pres-Decl
t'uj-go, kən-nin-da
'run and walk'
b. Type 2
Adults: stem-Conj, stem-Pres-Decl
kət-k'o, t'uj-n-da
'walk and run'
Younger children: stem-Conj, stem-Pres-Decl
kər-go, t'uj-n-d (the correct form: kət-k'o)
'walk and run'
Older children: stem-Deictic-Conj, stem-Deictic-Pres-Decl
kər-ə-ga-go, t'uj-ə-o-n-da

'walk away and run toward'

Both child and adult participants always inflected the two verbs in a coordinated sentence in morphologically parallel structures. Either both of the verbs in a sentence were inflected in adult forms as (a) and (b) in (81), or in extended forms as (c) in (81). The corresponding morphemes in the coordinated clauses are in squared brackets.

(81) The observed templates of paired-verb inflections

a. kət-k'o, t'uj-n-da
[Stem]-connective, [Stem]-tense-mood
'walk-and, run-pres-decl'

b. kət-koit-k'o, t'uj-goit-t'a
[Stem-prog]-connective, [Stem-prog]-tense-mood
'walk-and, run-pres-decl'

c. kəɾ-ə-o-go, t'uj-ə-ka-n-da
[Stem-conj-deictic]-connective, [Stem-conj-deictic]-tense-mood
'walk-toward-and, run-away-pres-decl'

As in Experiment 3, adults inflected all of the verbs in the form of either (a) or (b). The correct stem allomorphs in the two forms are C-stems, and adults produced the correct forms of C-stems with no exception.

Notably, children's selection between adult forms as (a) and (b) and a child form as (c) depended on the first verb of the sentence. When the first verb in a coordinated sentence was one that children preferred to inflect in an adult form in Experiment 3, they preferred to inflect the verb in a coordinated sentence using adult-like morphological structure in Experiment 4; when the first verb in a coordinated sentence was one that they preferred to inflect in one of the child forms in Experiment 1, they preferred to inflect the verb in a sentence using a child form in Experiment 4. I call a verb that children preferred to inflect in an adult form an 'adult-form-preferring verb'. If a verb is preferred to be inflected in one of the child forms, including both incorrect allomorphs and morphologically extended forms, I call the verb a 'child-form-preferring verb'.

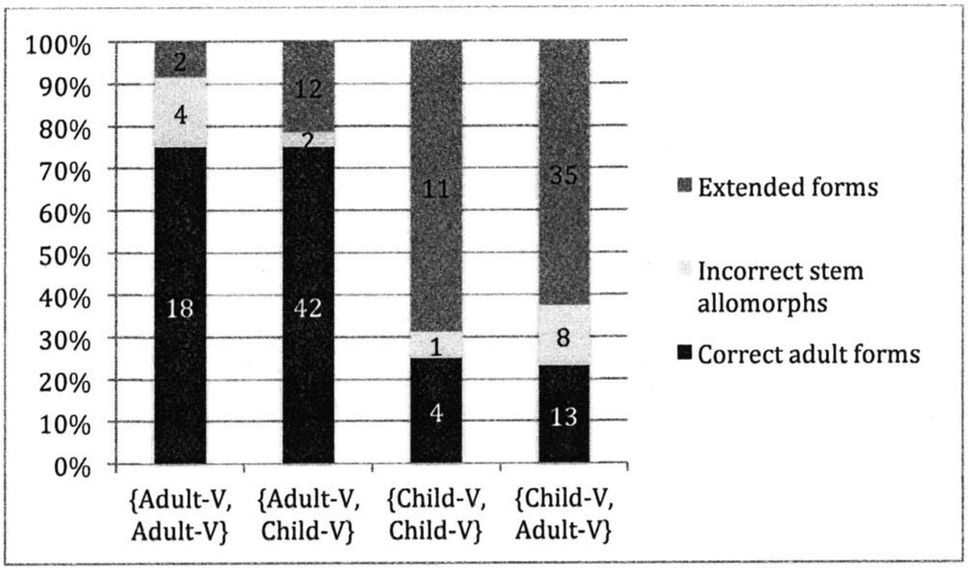
The results of Experiment 4 show that when children inflected an adult-form preferring verb in the first clause, the second verb in a sentence was also inflected in the templates of 'Stem-PROG-DECL' or 'Stem-PRESPROG-DECL'. Adult-form-preferring verbs in the second clauses were inflected with the correct adult forms both from younger children (18 out of 24) and from older children (33 out of 42). The first bars in the graphs (83) and (83) show the inflection patterns of adult-form-preferring verbs in the second clauses, when another adult-form-preferring verb was inflected in the first clause.

When child-form-preferring verbs occurred in the second clauses, following adult-form-preferring verbs in the first clause, children in the older group frequently inflected them with the correct adult forms. Crucially, this is different from the tendency observed from Experiment 3: children in older group preferred to inflect child-form-preferring verbs in extended forms in single picture description tasks. However, the result of Experiment 4 shows that children in the older group did frequently inflect child-form-preferring verbs with correct adult forms, when adult-form-preferring verbs were inflected in the first clause. Children in the younger group selected the incorrect stem allomorphs for the inflection of child-form-preferring verbs. The second bars in the graphs (83) and (83) show the inflection patterns of child-form-preferring verbs in the second clauses, when adult-form-preferring verbs were inflected in the first clause.

Inflection patterns of the second verbs were different, when child-form-preferring verbs were inflected first. Children in the older group preferred to inflect the second verbs in the extended templates as 'Stem-Conj-{Deictic, Epistemic, Directional...}-Decl'. Both child-form-preferring verbs and adult-form preferring verbs were frequently inflected with extended forms as shown in the third and fourth bars in the graph (82) and (83). Adult-forms were rarely inflected in extended forms in Experiment 3, but in Experiment 2, children in the older group inflected adult-form-preferring verbs in the second clauses with extended forms as well, when child-form-preferring verbs were inflected first.

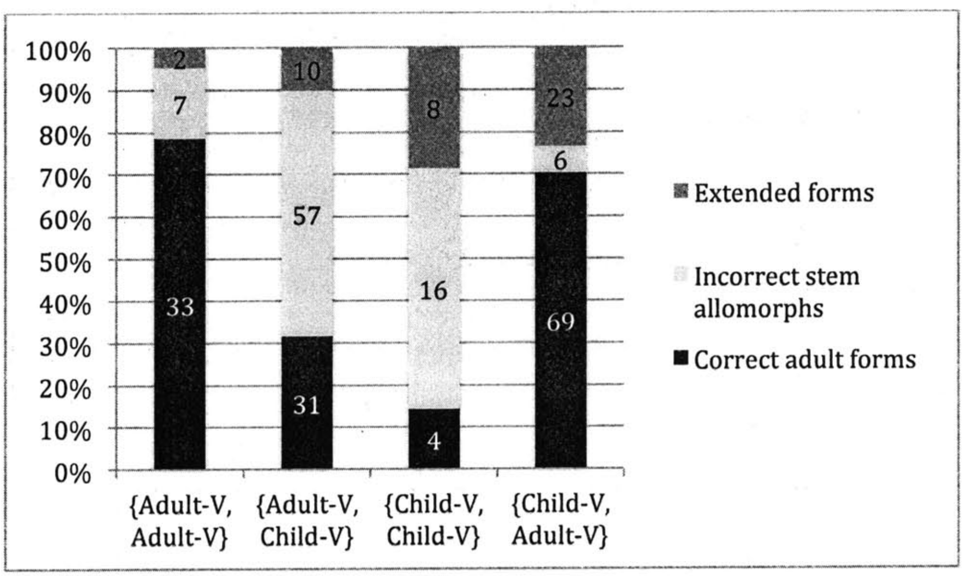
Unlike older children, the extended forms were not frequently produced by younger children. In other words, the verbal templates they frequently employed were 'STEM-PRES-DECL' and 'STEM-PRESPROG-DECL', but not 'STEM-CONJ-{DEICTIC, EPISTEMIC, DIRECTIONAL...}-DECL'. From their production employing the adult-form templates –i.e., 'STEM-PRES-DECL' and 'STEM-PRESPROG-DECL', incorrect forms were found predominantly from child-form-preferring verbs. Regardless of the first verbs, adult-form-preferring verbs in the second clauses were frequently inflected in the correct adult forms. The first and fourth bars in the graph (83) show the high frequency of the correct adult forms of adult-form-preferring verbs. Also regardless of the first verb, child-form-preferring verbs were frequently inflected with the incorrect stem allomorphs. The second and third bars in the graph (83) show this result.

(82) The distribution of inflection forms of the second verbs from older children



(Adult-V: adult-form-preferring verbs, Child-V: child-form-preferring verbs)

(83) The distribution of inflection forms of the second verbs from younger children



The pattern of incorrect stem allomorphs was identical with the one observed in Experiment 3: children wrongly selected the stem allomorph V-stem, where C-stem was required. An example is in (84). While an obstruent-initial suffix *–koit*, a present progressive morpheme, requires an obstruent-final stem allomorph *kət-*, the incorrect stem allomorph *kər-* was selected, which is found before V-initial suffixes.

All of the wrong stem allomorphs were V-stems, and no case was found that children incorrectly chose C-stems where V-stems are needed. This is the same pattern observed from Experiment 3.

(84) An answer involving an incorrect stem allomorph in the inflection of the second verb

t'uj-goit-k'o, **kər-ɨ-goit-t'a** (a correct stem allomorph: kət-)
[Stem-prog-connective, Stem-ɨ-prog-tense-mood
'walk-and, run-inserted vowel- pres-decl'

The table below summarizes the preferred patterns of paired-verbs' inflections among correct adult forms (Correct adult F), the template of adult forms involving incorrect stem allomorph (Incorrect adult F), and extended forms (Extended F).

(85)

	Younger children	Older children
{AdultV, ChildV}	{Correct adult F, Incorrect adult F}	{Correct adult F, Correct adult F}
{AdultV, AdultV}	{Correct adult F, Correct adult F}	{Correct adult F, Correct adult F}
{ChildV, ChildV}	{Incorrect adult F,Incorrect adult F}	{Extended F, Extended F}
{ChildV, AdultV}	{Incorrect adult F, Correct adult F}	{Extended F, Extended F}

(AdultV: adult-form-preferring verbs, ChildV: child-form-preferring verbs)

From 6 out of 38 stimuli, non-target verbal roots were observed. Unlike the results of Experiment 1, where alternative lexical choices systematically involve specific patterns of alternations, no such pattern was observed from non-target verbal roots in Experiment 2.

2.2.4.3 Discussion

Adults always inflected a verb employing non-extended verbal templates, with no exception. Many other verbal inflections are available to adult speakers, as introduced earlier in (63), but their choices were always the morphologically shortest or simplest inflectional forms. This pattern of adults' verbal inflection is understandable, considering that they chose the template of verbal inflection that can express the given context well with minimal effort. I will discuss this issue in detail in Chapter 3.

Children in the younger group also used non-extended verbal templates, but they incorrectly inflected child-form-preferring verbs. The pattern of errors was identical with the pattern observed in Experiment 1: younger children wrongly selected the Vstems instead of the Cstems.

From children in the older group, the inflectional patterns of a verb were systematically different depending on its position in a sentence. The first verb was inflected reflecting children's phonological preferences found in Experiment 3: they inflected an adult-form-preferring verb as an adult form, and a child-form preferring verb as an extended form. The second verb was inflected according to the inflectional template provided by the first verb. This result implies that the inflectional pattern of the first verb is free from structural restriction, while the second verb is not.

Notably, when an adult-form-preferring verb was first inflected using an non-extended verbal template, a child-form-preferring verb in the second clause was also inflected in the same way, and the outputs were almost always correct: as shown in the graphs above, only 2 instances out of 56 showed the incorrect inflection of child-form-preferring verbs. This indicates that children in the older group do know how to correctly inflect verbs, child-form-preferring verbs as well as adult-form-preferring verbs, using the adult templates. This result confirms that children's behavior in Experiment 1 are indeed motivated by their phonological preferences, not by their ignorance of adult forms: when children must use a given pattern of verbal inflection determined by the preceding verb due to the syntactic constraint, the inflection of the second verb in Experiment 4, they inflected verbs employing the adult template and errors were rarely found from such cases. However, when children are free to choose the pattern of verbal inflection reflecting their own preferences, all cases in Experiment 4 and the inflection of the 1st verb in Experiment 4, they deviated from adults for the inflection of some verbs. This is clear evidence showing that children do know the correct adult forms, but they avoid using adult forms for some specific verbs' inflection, when they are free to choose the preferred pattern of verbal inflection. The inspection of the child forms in the older group shows no instance that is incompatible with the given picture. For instance, children described the picture showing 'a walking man' variously as 'a man is moving', 'a man is walking forward', 'a man is walking toward me' or 'a man is trying to walk', all of which can be possible interpretations of the picture.

The patterns found from younger children in the younger group frequently created incorrect verbal forms. Thus, it does not seem to be the case that their knowledge about the correct adult form is as complete as older children. Presumably, they are exposed to the inflected forms of verbs less frequently than older children, hence they may not know the correct stem allomorph for each inflected form very well. So, their results seem to be partially explained by their incomplete knowledge of the adult language.

Importantly, both incorrect stem allomorphs and extended forms that children produced in two developmental stages show the same pattern, in that child forms are more faithful to the base form, the Vstem, compared to adult forms. This result indicates that children prefer to inflect forms faithfully to the base form, when there is no restriction imposed on their production.

2.3 When the OO-Corr bias is suppressed

The two preceding sections (§2.1, §2.2) showed that child speakers have a phonological preference to maintain paradigm uniformity due to a priori higher ranking of OO-CORR constraints than markedness constraints. As we observed, however, the phonological preference (i.e., avoiding alternations) was not always reflected in their production; children produced phonologically dispreferred forms (i.e., alternating forms) when a language-specific syntactic constraint was imposed on the sentences they process. Specifically, for the sake of making the morphological structure of two coordinated clauses in a sentence parallel, children produced phonologically alternating forms. For instance, consider a sentence in which two verbs are coordinated. Suppose that adult-like inflection of the first verb does not cause alternations, while that of the second verb does; the first verb is 'an adult-form-preferring verb' and the second one is 'a child-form-preferring verb'. Even though they would like to inflect the second verb in a child-form in the interest of avoiding alternations, children actually inflected the second verb in an adult form, in the situation when they need to satisfy a syntactic constraint 'Parallel'.

For the moment, I assume that non-adult-like forms are morphologically marked, and I assign one violation for a cover Markedness constraint for every child form. Since we assume that child forms do not involve an alternation, they satisfy a cover OO-CORR constraint. Adult forms are, on the contrary, assumed to be morphologically unmarked, and violate an OO-CORR constraint. The analysis of how morphology can be negotiated to satisfy a phonological preference of the speakers will be a main topic of the following chapter.

Under the constraint ranking presented in the tableaux (87) and (88), no option is left to produce the combination of an adult form and a child form as in candidates (c) and (d), due to the undominated constraint Parallel. Notably, the experimental results showed that the produced forms are different depending on the first conjunct of a sentence, but not on the second conjunct: child speakers produced two adult forms when the adult-form-preferring item comes first, and they produced two child forms when the child-form-preferring items comes first. I formulate the tendency that speakers reflect their phonological preference of the first conjunct to the inflection of both conjuncts in a sentence in the following way;

(86) PHON1ST: The phonologically preferred way of inflecting the first conjunct should be respected.

The constraint Phon1st must outrank the OO-CORR constraint; otherwise, the candidate (b) will be selected in all tableaux below, since it preserves paradigm uniformity while adult forms do not.

(87) When an adult-form-preferring verb comes first in a sentence

/Adult-form-preferring V, Child-form-preferring V /	PARALLEL	PHON1ST	OO-CORR	MARKEDNESS
☞a. [Adult form, Adult form]			**	
b. [Child form, Child form]		*!		**
c. [Adult form, Child form]	*!			*
d. [Child form, Adult form]	*!	*		*
/Adult-form-preferring V, Adult-form-preferring V /	**PARALLEL**	**PHON1ST**	**OO-CORR**	**MARKEDNESS**
☞a. [Adult form, Adult form]			**	
b. [Child form, Child form]		*!		**
c. [Adult form, Child form]	*!			*
d. [Child form, Adult form]	*!	*		*

(88) When a child-form-preferring verb comes first in a sentence

/Child-form-preferring V, Adult-form-preferring V /	PARALLEL	PHON1ST	OO-CORR	MARKEDNESS
a. [Adult form, Adult form]		*!	**	
☞b. [Child form, Child form]				**
c. [Adult form, Child form]	*!	*		*
d. [Child form, Adult form]	*!			*
/Child-form-preferring V, Child-form-preferring V /	**PARALLEL**	**PHON1ST**	**OO-CORR**	**MARKEDNESS**
a. [Adult form, Adult form]		*!	**	
☞b. [Child form, Child form]				**
c. [Adult form, Child form]	*!	*		*
d. [Child form, Adult form]	*!			*

The ordering effect on the inflection of items indicates that there is a systematic direction of morphological construction: the second item in a sentence was inflected according to the inflectional template of the first item, but not vice versa. Korean speakers do not make use of phonological information from the right context, at the temporal point when they construct a morphological form in the left context; the morphological form of the first item of a sentence is determined, without anticipating the phonological preference of the second item. As a consequence, the phonological preference of the second conjunct may be overridden. Once the first item is inflected, this inflectional template is provided to the second item, as in (89). Speakers insert lexical items into the morphological slots of the second conjunct which are already determined by the first conjunct.

(89) Temporal sequencing of sentence process

Visual stimulus: *'running, walking'*

Construct the structure of the fist item reflecting phonological preference of the item: [tji]-go, _________. 'run-and, ______.'

Provide the template to the second item: [tji]-go, [Vstem]-Pres-Decl.

Insert lexicl items to the second conjunct: tji-go, kən-nɨn-da. run-and, walk-pre-decl.

Why is it always the first item that serves as the base of morphological structure of coordinated items? What makes speakers not anticipate the phonological preference of the second item when they decide the morphological structure of the first item? It needs further investigation about sentence production to see the maximum distance of the information that people can draw from the right context to specify an analysis of the sentence at the left context.

3 Paradigm uniformity, Economy and Expressiveness

The preceding chapter reported that child speakers who are in the early stages of acquiring phonological alternations produce morphologically deviant forms, --either morphologically more complex forms (e.g., *kərə-ga-* 'walk-toward' instead of *kət-* 'walk') or the forms missing morphological components that are normally expressed in adult forms (e.g., *pit* 'light' instead of *pitʃʰ-i* 'light-NOM')--, or lexically deviant forms (e.g., *ga-* 'move' instead *kət-* 'walk') due to their interest of avoiding phonological alternation. The argument was that such production tendency is rooted in the initial OO-CORR bias.

Broadly speaking, a phonological learning bias is affecting the selection of morphological template and the selection of lexical items in the production of child speakers. How do we need to understand this interaction of phonology, morphology, and lexical information? Which perspectives of speakers' morphological preference or lexical knowledge are negotiated, and why specifically do those aspects become the target of the negotiation while others do not?

This chapter develops the formal analysis of morphologically and lexically deviant forms in children's production, incorporating the data from the previous chapter. I propose that the deviant forms observed from children are the outcome of negotiating the economy of production with preserving paradigm uniformity. For instance, children insert extra morphemes in the inflection of items, and thus create less economical forms in order to render the forms non-alternating. It is demonstrated that children violate the economy of production constraint as minimally as possible, so far as the outcome allows them to avoid alternations; for example, if employing one additional morpheme in the inflection of an item can already make the form identical to the base, children never insert more than one morpheme. Crucially, all of the repaired forms produced by children were still compatible with the given visual stimuli. I argue that speakers generate multiple expressions that are compatible with the semantic features of the visual stimulus (expressiveness), and produce the simplest one (economy) that does not incur an alternation (satisfaction of paradigm uniformity). The analysis makes use of Economy and Expressiveness constraints proposed by Kiparsky (2005), constraints that formalize the notion that the simplest and the most expressive expression is preferred over others when multiple expressions competes with each other. I briefly introduce Kiparsky's proposal, and then analyze the production data presented in Chapter 2.

3.1 Economy & Expressiveness

Kiparsky (2005) proposes the constraints Economy and Expressiveness to account for the blocking mechanism. Following an assumption in Lexicalist Morphology, Kiparsky considers that the grammar consists of two pieces: a generative component and a filter (Wunderlich 1996). Speakers generate expressions by the components of the lexicon, morphology, and syntax. A potentially unlimited set of expressions is generated, and they compete with each other. Potential candidates refer to the expressions that are compatible with the intended meaning, so far as syntax and morphology permit. It is a filter that serves as the blocking mechanism: non-optimal candidates are filtered out. The filter in the blocking mechanism consists of two constraints (Kiparsky 2005:2) in (90);

(90) The filter in Lexicalist Morphology

Economy: Avoid complexity
Expressiveness: Express meaning

Economy, in OT terms, is a markedness constraint that requires that the simplest expressions be chosen, other things being equal. In considering word-formation in inflectional paradigms, complexity may be measured by the number of morphemes. Expressiveness is a faithfulness constraint that requires every meaning in the input be expressed in the output, other things being equal.

To see how Economy and Expressiveness play a role in selecting the optimal expression, consider the competition between *happier* and the possible expression *more happy*. Assuming that *happy* is listed in the lexicon, Kiparsky assumes that *happier* is generated by the morphology, and *more happy* is generated by syntax. *Happier* and *more happy* are equally expressive expressions, given that they mean the same thing –i.e., comparative expressions of the status of feeling pleasure. *More* in *more happy* adds syntactic structure, leading to a violation of economy that is more severe than the violation caused by *-er*, which only adds morphological structure; thus *happier* wins.

Happy may be a competing expression with *happier* as well. If Economy is measured by the number of morphemes, a single-morpheme expression *happy* is better than a two-morpheme expression *happier*. However, *happy* does not denote the semantic content of the comparative, thus it violates Expressiveness. Therefor *happier* is selected as the optimal expression.

3.2 Production of less economical forms for paradigm uniformity

Recall that the experiments in Chapter 2 found three types of child speakers' deviant inflectional forms as in (91). Such forms were found predominantly in the situations in which adult-like inflections involve alternations, and alternatively selected deviant forms do not exhibit an alternation –i.e., forms have the stem variants that are faithful to the stem found in the base form of the paradigm.

(91) Types of deviant forms

Types	Examples of deviant forms	Examples of adult forms
Morphologically more complex forms	kərə-ga-n-da 'walk-go-pres-decl'	kən-nɨn-da 'walk-pres-decl'
Forms missing optional morphological components	pat 'field'	patʃʰ-i 'field-Nom'
Lexically deviant forms	tji-n-da 'run-pres-decl'	kən-nɨn-da 'walk-pres-decl'

Children did produce adult-like inflected forms when the inflection does not involve an alternation. Thus the deviant inflectional forms observed from child speakers are not the result of their ignorance of adult-like inflections, but the result of repairs which are employed for a phonological purpose–i.e., children's interest to preserve paradigm uniformity. What is the child speakers' reasoning behind the production of such deviant forms?

When speakers are faced with a visual stimulus, they generate their interpretations of it. I assume that the interpretations are the bundle of all semantic features that are compatible with the stimulus. Suppose a speaker sees *a rolling ball* as in (92).

(92) A schematic picture of producing an output

a. Interpretation	{ball roll down hill fast … etc.}		
	Expression 1	Expression 2	Expression 3
b. Semantic features	ROLL	ROLL DOWN	FLY
c. Lexical entries	'kullə'	'kullə' 'neɾjə'	'naɾa'
d. Segments	kuɾɨ-n-da	kullə-neɾjəga-n-da	na-n-da
	'roll-pres-decl'	'roll-down-pres-decl'	'fly-pres-decl'

For the visual stimulus in (92), a semantic feature such as 'fly' is not compatible with the scene, thus it is not included in the bundle of the interpretation; Expression 3 is not valid expression for this visual stimulus. On the other hand, semantic features as the ones in the interpretation in (92) –e.g., 'roll' or 'down', are compatible with the scene. Following Kiparsky's definition (2005), I consider that the potential expressions composed of the semantic features that are compatible with the (visual) stimulus satisfy Expressiveness. In our example in (92), Expression 3 violates the Expressiveness constraint.

(93) Expressiveness Express meaning that is only compatible with the given stimulus

Various combinations of the semantic features create multiple expressions that can describe the visual stimulus. For instance, the expression 'a ball is rolling down' is a potential expression, and so is 'a ball is rolling'. I suppose that all of the semantic features compatible with the stimulus are generated at the level of interpretation. Even if other expressions that use semantic features which are not in the interpretation level are generated, as Expression 3 in our example, they are filtered out by the undominated Expressiveness constraint. So far as an expression is composed of the features within the bundle of the interpretation, it satisfies the Expressiveness constraint.

Once speakers pick out the semantic features that will be involved in each expression, they select lexical entries for the corresponding semantic features. In (92), for example, *kull-ə* is the selected lexical entry for the semantic feature 'roll'. It is likely that there are multiple lexical entries that are available to denote the intended meaning. For instance in Korean, the semantic feature of 'down' can be expressed with the verbal morphemes such as *neɾjəga*[9], *hagaŋha*, etc., denoting that 'a ball is descending the hill by rolling'. I will assume that speakers select the most appropriate lexical entry, considering the entire context of the visual stimulus –e.g., if a scene is showing 'a ball' moving downward, it is appropriate to use *neɾjə*, but it is unnatural to use *hagaŋ ha*, because the former is used for the downward motion of an

[9] 'neɾjəga' is composed of two morphemes: 'neɾjə' down and 'ga' go. Because the morpheme 'neɾjə' cannot stand alone and should be followed by a default motion verb 'ga', I do not further decompose 'neɾjəga' into 'neɾjə' and 'ga' for the purpose of the current consideration. See Zubizarreta and Oh (2007) for the detailed analysis of motion-verb constructions in Korean.

object moving on a surface, while the latter is used when a moving object is not attached to a surface -- e.g., the downward movement of elevators, airplanes etc.

Once lexical entries are selected, speakers construct a string composed of segments, morphology and syntax permitting. Morphology and syntax determine the order of the morphemes –e.g., *kullə* 'roll' comes before *neɾjəga* 'down'. When a morpheme has phonological allomorphs, phonological evaluation selects the proper one depending on its morphological and syntactic structure.

The generated strings such as (a) *kuɾi-n-da* 'roll-pres-decl', (b) *kullə-neɾjəga-n-da* 'roll-down-pres-decl', and (c) *na-n-da* 'fly-pres-decl' are competing with each other, and the Expressiveness constraint defined in (93), the Economy constraint, and OO-CORR constraints regulating paradigm uniformity participate in the evaluation of the candidates. As a specified version of Economy proposed by Kiparsky in (90), I define Economy as follows;

(94) Economy If expression 1 has fewer morphemes than expression 2, then expression 1 is optimal.

The definition above adopts the view of the Economy constraint proposed by Katzir (2008, 2011), in that the quantitative measure of complexity, such as the number of morphemes, is a determining factor of the output, other things being equal.

Expressiveness must be undominated; otherwise, the constraint ranking incorrectly predicts that the expression whose meaning is not compatible with the visual stimulus may win, such as the expression denoting the ball's movement as 'flying' in the example in (92).

As far as expressions are compatible with the scene, they are considered to be equally expressive. I will shortly come back to this issue in the following section. Among the equally expressive expressions, for example Expression 1 and Expression 2 in (92), the expression involving fewer morphemes is optimal. In (92), candidate (a) wins over candidate (b), since expression (a) has one less morpheme than (b). This constraint ranking reflects the idea that speakers would like to produce a form as simply as possible, so far as the meaning of the form is compatible with the given stimulus.

(95) Production of the simplest and expressive expression

	Expressiveness	Economy
☞a. kuɾi-n-da 'roll-PRES-DECL'		***
b. kull-ə-neɾjəga-n-da 'roll-CN-down-PRES-DECL'		****
c. na-n-da 'fly- PRES-DECL'	*!	***

The experimental results provided evidence supporting the undominated status of Expressiveness in child speakers' phonological grammar as well; children sometimes responded with unusual expressions that are rarely found in the adult language, but all such forms were compatible with the given stimuli. When they inserted extra morphemes in inflection, those supplied additional meanings to the stimulus, which adults normally do not express. For instance, in tableau (95), adults did not express the semantic feature 'down' for the movement of a ball as in candidate (a), but children did express a verbal morpheme for 'down' in verbal inflection as shown in candidate (b), because the expression without the morpheme for 'down' incurs the stem-final segment's alternation. Expressing the 'downward' direction of the ball's movement may not be necessary, since listeners can normally infer the information in the absence of it, but interpreting the ball's movement shown in (92) as 'rolling down' is obviously a 'compatible' interpretation of the stimulus. This shows that child speakers always produced expressive forms or the forms that are compatible with the scenes.

OO-CORR constraints outrank the Economy constraint in the initial state of children's phonological grammar. In other words, paradigm uniformity, which is preserved by producing non-alternating forms, is more important than the simplicity of expression to child speakers, when they begin to learn how to inflect items. For instance, in (96), expression (b) uses the stem found in the base form, but the stem-final consonant [ɾ] alternates with [n] in expression (a): the base form (A-suffixed form) of the verb *roll* is 'kəɾ-ə'. Since an OO-CORR constraint outranks Economy in children's phonological grammar, expression (b) is optimal even though it has more morphemes than expression (a).

(96) Evaluation by child speakers

	Expressiveness	OO-Corr	Economy
a. kuɾɨ-n-da 'roll-pres-decl'		*!	***
☞b. kull-ə-neɾjəga-n-da 'roll-down-pres-decl'			****
c. na-n-da 'fly-pres-decl'	*!	*	***
Bases: kull- 'roll' nal- 'fly'			

The constraint ranking in (96) indicates that child speakers violate Economy of expressions in order to avoid alternations. Such a tendency was not found from adults. Rather they produced simpler forms which involve phonological alternations; Economy outranks OO-CORR constraints in adults' grammar. Crucially, the winner selected by child speakers as (b) includes additional morphemes compared to the adult form as (a) as *minimally* as possible; no instance was found in which children inserted excessive extra morphemes in order to produce non-alternating forms. For instance, an expression that uses the stem in the base form such as *kullə-neɾjəga-nin-cuŋ-ida* 'roll-down-Pres-Prog-be', might have also been employed to create a form satisfying an OO-CORR constraint, but such a excessively complex forms were never attested from child participants. Children always inserted the minimal number of necessary morphemes. That is, children do indeed consider Economy of expressions when they find alternative ways to inflect forms incorporating additional morphemes.

Another attested way of avoiding alternations was avoiding morphological components that incur alternations. Specifically, children omitted optional case markers of nouns as repeated in (97). In this example, adult speakers alternated /patʰ/ 'field' with the variants as in the table below, but child speakers preferred not to suffix the nominative marker, and realized /patʰ/ as [pat] by using the stem found in the base form [pat].

(97) Omission of optional case markers

Types	Examples of deviant forms	Examples of adult forms
Omission of the nominative marker	pat 'field'	patʃʰ-i ~ paʃ-i ~ padʒ-i 'field-Nom'
Omission of the accusative marker	pat 'field'	patʰ-ɨl ~ patʃʰ-ɨl ~ pas-ɨl ~ padʒ-ɨl 'field-Acc'

Omission of the nominative and the accusative markers is permitted in this context by Korean syntax, and the expressions still satisfy Expressiveness. Recall that in the experimental stimulus all other sentence components except for the target word were given. Thus, the grammatical role of one item in a sentence, which is missing the case marker, is obvious. For instance in (98), where the transitive verb 'plow' requires a subject and an object, the unsuffixed noun 'field' must be interpreted as an object due to the nominative case marker on 'farmer'; there is no way that the sentence can be interpreted as 'the field plows a farmer', which is incompatible with the given stimulus.

(98) noŋbu-ga pat ka-n-da.

'farmer-Nom field plow-pres-decl'
A farmer plows the field.

The requirement of realizing the nominative and the accusative case marker is formulated as (99). I refer to this constraint as Realize Nominative/Accusative or RealNom/Acc constraint. This constraint penalizes the omission of the nominative and the accusative markers. Since the case marking of the nominative and the accusative are optional in the language, this constraint must be low in the constraint ranking.

(99) RealNom/Acc Realize the nominative/the accusative case markers.

As pointed out, omission of the case markers is another way that children preserve paradigm uniformity; sometimes they inserted extra morphemes and sometimes they omitted the case marker. This suggests that the ranking of Economy and RealizeNom/Acc varies from production to production. When Economy outranks RealizeAcc in (100), a morphologically more complex form, such as in candidate (b), is produced. When the ranking of the two constraints is the opposite, the form missing a case marker, such as candidate (a) is the winner.

(100)

	Expressiveness	OO-Corr	Economy	RealizeAcc
☞a. pat 'field'			*	*
☞b. pat an-il 'field-inside-Acc'			***	
c. pas-il'field-Acc'		*!	**	
Base: pat 'field'				

Different lexical items were frequently selected, especially when the inflection of the lexical item selected by adults incurs alternations. However, alternatively selected lexical items were not the ones that are completely incompatible with the visual stimulus. The attested three types of lexically deviant forms are provided in (101). Crucially, the inflections of lexical items in deviant forms do not involve alternations: the sonorant-final stem [t'aŋ] 'earth', the vowel-final stem [tji] 'run' stem, and coronal obstruent-final stem with the neutralized [t], [pat] 'field' are faithful to the stems of their base forms.

(101) Types of lexically deviant forms

Types	Examples of deviant forms	Examples of adult forms
Different noun stems	t'aŋ-i 'earth-Nom'	patʃʰ-i ~ paʃ-i ~ padʒ-i 'field-Nom'
Different noun suffixes	pat-hantʰe 'field-to'	patʰ-e ~ patʃʰ-e ~ pas-e ~ padʒ-e 'field-to'
Different verb stems	tji-n-da 'run-pres-decl'	kən-nin-da 'walk-pres-decl'

As shown, lexical items in deviant forms may express a meaning similar to the meaning denoted by the adult forms. For the moment, I assume that 'running' is a compatible interpretation of 'walking', because participants were shown non-animate pictures in the current experiments; no speed of the motion was explicitly shown. I will come back to this issue shortly.

Adult participants reliably inferred the speed of the motion from additional information they inferred from the visual stimulus --e.g., facial expressions of the person, the angle between the legs etc. For instance, when a person in the scene is sweating and moving his arms and legs relatively actively as in (102), all of the adults interpreted the stimulus as the person is running, not walking.

(102)

The motion in (102)should be interpreted as locomotion, thus no interpretation such as *sing* or *sleep* is compatible. Also, the interpretation with completely different manners of motion such as *fly* is incompatible with the visual stimulus as well. The speed of the motion, however, could be at most inferred, but is not explicitly provided in the visual stimulus; *run* is a better interpretation considering additional semantic features in the visual stimulus, but *walk* is not as bad as *sing* or *fly* as an interpretation of (102). In order to distinguish different levels of incompatibility, I split Expressiveness into various degrees. For instance, Expressiveness 1 penalizes completely incompatible interpretations, while Expressiveness 2 is violated only by the ones whose contextual information makes them not the optimal interpretation of the visual stimulus –e.g., *walk* violates Expressiveness 2 because the speed of the motion does not match with the optimal interpretation *run*, or *earth* in (101) violates Expressiveness 2 because the expression involves too broad range of various locations (e.g., field, ground, mountain etc.), while the context provided enough evidence to consider that the location is specifically *field*. For current purposes, I do not further discuss the detailed degree of Expressiveness constraints and which semantic features should belong to which constraint. See the following section for a follow-up experiment I conducted to investigate how child speakers' production patterns become different when implicit information penalized by Expressiveness 2 (e.g., the speed of the motion) was explicitly given in the visual stimulus.

Expressiveness 2 must be ranked lower than Expressiveness 1, which penalizes completely incompatible interpretations. Some instances of children's production exhibited lexically deviant forms, while some showed morphologically more complex expressions in verb inflection; thus, the ranking of Economy and Expressiveness 2 varies for each production instance.

(103)

	Exp1	OO-Corr	Economy	Ex2
a. kən-nɨn-da 'walk-pres-decl'		*!	***	
☞b. kərə-ga-n-da 'walk-dectic-pres-decl'			****	
c. na-n-da 'fly-pres-decl'	*!	*!	***	
c. noreha-n-da 'sing-pres-decl'	*!		***	
☞d. tji-n-da 'run-pres-decl'			***	*
Bases: kərə 'walk' nalla 'fly' noreha 'sing' tji 'run'				

In noun inflection, three options of avoiding alternations were attested: inserting extra morphemes, omitting the nominative or the accusative case markers, and selecting alternative lexical items –i.e., the ranking of Economy, RealizeNom/Acc, and Exp2 determines the outcome for each case of production.

(104)

	Exp 1	OO-Corr	Economy	RealizeAcc	Exp2
☞a. pat 'field'			*	*	
☞b. pad-an-ɨl 'field-inside-Acc'			***		
c. pas-ɨl'field-Acc'		*!	**		
d. pada-ɾɨl'sea-Acc'	*!		**		
☞e. t'aŋ-ɨl'earth-Acc'			**		*
Bases: pat 'field' pada 'sea' t'aŋ 'earth'					

3.3 Economy & Expressiveness in production

In the previous section, I assumed that alternative lexical choices are compatible with the visual stimulus but not optimal for adults given that they do not match with the implicit information one can infer from the context –e.g., an expression 'walking' is less proper than 'running' for the visual stimulus involving indications of fast movement such as sweat on a person's face, hair blowing in the wind etc. I argued that children chose minimally less expressive forms in the interest of reflecting their phonological preference in production, namely maintaining paradigm uniformity. Broadly speaking, child speakers trade relatively less important expressiveness (Expressiveness 2) for phonological purposes; they never selected lexical items completely incompatible with the visual stimulus—i.e., no violation of Expressiveness 1 was incurred.

Recall that the stimuli in the experiments were shown as inanimate pictures, thus much room was left for speakers to infer information related to the visual stimuli. Especially in the experiment eliciting verbs, the interpretation of the directions, the speeds, and the goals of depicted motions were subject to each participant's understanding of the stimuli –e.g., picture (102) may be interpreted as a running motion, or as a walking motion. If the speed of the locomotion in (102) is given explicitly in the visual stimulus, how will child speakers describe the picture? In other words, if the visual stimulus provides sufficient information indicating that the person in (102) is running, not walking, will children treat the speed of the motion as a component of the meaning that cannot be overruled (Expressiveness 1) by phonological interests? Informally, I predict that children will not deviate from adults in their lexical choices, when the direction and the speed of the motions are not subject to their inference, but rather compatible specifically with one interpretation; thus the alternative lexical choices attested in the current experiment can be attributed to their negotiation of implicit semantic features with the phonological preference of creating non-alternating forms. This hypothesis is presented below.

(105) Hypothesis 1

If the semantic feature [+F] is explicitly presented in the visual stimulus, the production cannot reflect this component as [-F]. Only when the semantic feature [+F] is implicit in the visual stimulus, may it be expressed as [-F] in order to satisfy phonological constraints.

Also note that all of the motions depicted in the current experiment showed 'inferable' directions of the motions. For instance, a walking man was moving forward, not backward. Adult speakers never expressed inferable information in their production, creating more economical forms, and child speakers preferred to insert directional morphemes only when alternations would otherwise have occurred. When non-inferable information is provided in the visual stimulus, will speakers still try to satisfy Economy? In other words, do speakers consistently prefer to produce simpler forms regardless of the inferability of information? The hypothesis is that non-inferable information will be treated as the salient components that speakers should express (Expressiveness1), thus it should not be negotiated with Economy. This hypothesis is in (106).

(106) Hypothesis 2

If the semantic feature [F] is inferable, it may not be produced for simplicity of expression. However, when the semantic feature [F] is less inferable by the listeners, it is more likely to be produced.

In Do (2012), I tested the patterns of children's verbal inflection, this time, with animated clips. I examined the production patterns of motion events and explicitly showed the direction and the speed of the motions. Some of the stimuli were showed inferable direction, and some non-inferable directions. Since the main focus of Do (2012) was to figure out the correlation between morphosyntactic complexity of the verbal construction and the encoding of components in the verbal construction, I will not report the specifics here. The result relevant to the current purpose is as follows; the hypothesis in (105) was borne out. For instance, when a clip showed a man running at a fast speed, child speakers described the clip as the man is running, but not walking. The hypothesis in (106) was partially borne out as well. It was found in general that less inferable semantic features are more likely to be produced, but the experiment also found that the expression of less inferable information was significantly affected by morphosyntactic constraints as well, which I do not discuss here.

What is important for the current discussion is that children indeed looked for alternative lexical items which enable them to use phonologically non-alternating forms, by slightly changing semantic features which are implicit in the visual stimulus, thus still compatible (expressive) with the given information. Also, speakers by default prefer to produce expressions as simply as possible, but they do tend to express less-inferable information, even though the output results in morphologically more complex forms.

3.4 The OO-CORR bias, Expressiveness, Economy and learning

Concerning the natural learning setting, can the formalization in this chapter be a realistic way that children actually learn to produce adult forms? In other words, from the initial constraint ranking that OO-CORR constraints outrank Economy, RealizeNom/Acc, and Expressiveness2, can learners arrive at the final adult stage where OO-CORR constraints are demoted below those constraints?

OT approaches to learning assume that grammars are learned based only on positive evidence (Hayes 2004, Prince and Tesar 2004). So the question is how learners reach the adult grammar, where Economy, RealizeNom/Acc, and Expressiveness2 outrank OO-CORR constraints only from positive evidence. This means that child learners should allow alternations only when supported by the data. As learners find a wide variety of alternations during acquisition, the adjustment of the constraint ranking seems to be realistic. For instance, Korean-learning children first assume no alternation, but they find many violations of the OO-CORR constraint for the nasality feature based on the forms in which obstruent-final stems alternates with nasal in pre-nasal positions. Once the OO-CORR [±nas] constraint is demoted below Economy, RealizeNom/Acc, and Expressiveness2, learners are able to produce morphologically simpler forms, nouns with explicit case markers in formal or written contexts, and the forms most compatible with the visual stimulus, which incorporate contextual evidence for the interpretation, as adult speakers do.

4 Selecting bases in early stages

Children's production data in Chapter 2 and Chapter 3 show a systematic way that they avoid phonological alternations: one slot of the paradigm serves as the privileged form and children inflect other forms to be faithful to the form in that specific slot. Theoretically, children could have attained a globally harmonic paradigm (e.g., Optimal Paradigm: McCarthy 2005). Instead, the current experimental data showed that child learners systematically satisfy OO-CORR constraints in an *asymmetrical* way. This implies that children treat OO-CORR constraints as an asymmetrical relation (Benua 1997, Kenstowicz 1998, and others). As introduced in Chapter 1, such asymmetries are not unusual in child productions (Spanish: Clahsen, Aveledo, and Roca 2002, German: Clahsen, Prüfert, and Eisenbeiß 2002, Portuguese: Stoel-Gammon 1979 cited in in Bybee 1985). For example, Portuguese-learning children systematically innovate the 1sg verb on the model of the 3sg indicative in the course of regularizing the verb paradigm (Stoel-Gammon 1979).

4.1 How to select bases?

If children satisfy OO-CORR constraints in an asymmetrical way, on what basis do learners select one specific form over others as the privileged base form? In the case of Korean, why does an unsuffixed form serve as the base form of noun paradigms, and why is it an A-suffixed form (i.e., -a/-ə suffixed form) for verb paradigms?

A potential factor is their high token frequencies. In Korean, the unsuffixed noun form and the A-suffixed verb form show the highest token frequency among inflected forms. As claimed by Mańczak (1958), less frequent forms may be potentially reanalyzed on the basis of more frequent forms within the paradigm. However, other reported cases suggest that token frequency may not be the only factor in determining the base status of a form. The acquisition studies of Spanish (Clahsen, Aveledo, and Roca 2002) and of German (Clahsen, Prüfert, and Eisenbeiß 2002) provide good counterevidence for the claim that frequency alone determines the base status of a form. Both of the studies show that the most frequent third person singular form is reanalyzed based on less frequent third person plural or non-third person forms. In adult languages, the direction of the reanalysis is not always predictable by token frequency either (see Chapter 2 of Albright 2002 for discussion).

Broad occurrence in a variety of grammatical or semantic contexts also makes these forms potential candidates for the base form. According to Kuryłowicz (1947), forms with a 'broad sphere of usage' are likely to serve as the base form of analogical changes. Given that nominative, accusative and dative case markings are optional in Korean, and speakers actually prefer to omit the case markers in spoken language in many contexts, children find unsuffixed noun forms in a variety of grammatical contexts. The A-suffixed form is used for imperative, interrogative and declarative forms, and the A-suffixes also serve as a connective morpheme between the verbal root and following past tense, aspectual, gerund, and conditional morphemes. Thus children have multiple chances to detect the A-suffixed verb form in various grammatical and semantic contexts. However, evidence discussed in Albright (2002) suggests that frequency of occurrence alone cannot account for the direction of phonological reanalysis.

In response to the problem that frequency is insufficient to predict the base form of the paradigm, Albright (2002) proposes that the phonological informativeness of the forms is a crucial factor in selecting the base form. Learners select the maximally informative form, i.e. the form that exhibits as many contrasts and allows the learners to generate as many inflected forms of as many words as possible with the maximum accuracy.

In the current acquisition study, the production data elicited from young learners involves incorrect stem allomorphs: children produced suffixed noun forms using the stems found in the unsuffixed nouns and they produced non-A-suffixed verb forms using the stem found in A-suffixed verb forms. Children in intermediate acquisition stages employ a conspiracy of repairs, which also uses the same stems, a phenomenon found in both noun and verb inflections. Do children produce errors in early stages and then the repaired forms in later stages, as the result of a reanalysis based on phonologically most informative base form of the paradigm?

The unsuffixed form and the A-suffixed form are indeed claimed to be the most informative form of Korean noun paradigms (Albright 2008) and of Korean verb paradigms (Albright and Kang 2006). Computational modeling of learning inflected forms using the Minimal Generalization Learning algorithm (Albright and Hayes 2002, 2003) found that the unsuffixed form and the A-suffixed form correctly predict the other forms in the paradigm at a higher rate than other inflected forms.

It is worth noting, though, that the learning simulations in Albright (2008) and Albright and Kang (2006) are based on adult lexicons, (unrealistically) assuming that every inflected form of every word in the lexicon is equally available to the learners. For child learners, the actual learning situation is different. On average, learners encounter common words more than rare words (e.g., *eat* more often than *digest*). Also, learners are confronted with certain parts of the paradigm more often than other parts (e.g., in verb paradigms, it is most often the 3sg across all languages, according to Bybee 1985). Chan (2008) counts the types of inflected verbal forms found in CHILDES for three languages and reports that full paradigms never appear: 83.6% of possible verbal inflection forms were found in CHILDES Spanish, 69.2% in

CHILDES Catalan, and 63.3% in CHILDES Italian. Thus theoretically, learners in certain intermediate stages may never have encountered some inflected forms of the paradigm. And even if they may have heard the entire paradigm, child learners hear a rare inflection of an uncommon word less frequently than a frequent inflection of a common word. How will learners choose base forms when less common words are not well represented, and possibly when they may not have figured out full paradigms yet? If the learning is on the basis of such a limited set of data, will the induced phonological mapping process still be statistically reliable?

This chapter presents two distinct cases considering the relation between phonological informativeness and frequency. Korean noun paradigms show that the phonologically most informative form happens to also be the most frequent one and thus it is always selected as the base. But these two factors are not correlated in Korean verb paradigms; the most frequent form is actually phonologically least informative. I show that very high frequency of a form is sufficient to flip the preference to select a less informative form as the base. Based on empirical observations of child-directed utterances, I propose that semantic and pragmatic factors also play a role in scaling up the reliability of the form.

4.1.1 When the most available form is phonologically most informative

Recall that the unsuffixed form is selected as the most reliable choice to construct other forms of Korean noun paradigms from the simulation assuming that all words are equally available to the learner in all inflected forms (Albright 2008). As noted by Albright, that may not be true in actual learning situations. Schematically, the available learning data to children in real life is illustrated in (107). In Korean noun paradigms, for instance, counts from the Sejong Corpus of written Korean reveal that unsuffixed, nominative, and accusative forms are the three most frequent parts of the paradigm in the adult language. Among the three inflected forms, the unsuffixed form is most frequent followed by the nominative form, and the accusative form is least frequent. Thus, child learners have frequent access to the unsuffixed form of most of lexical items. For instance, not only are the unsuffixed forms of very common nouns in Korean, such as *saram* 'person' or *ʃigan* 'time' are available, but also the unsuffixed form of rare items, such as *tʃaŋə* 'sardine' or *moru* 'anvil' may be available to child learners as well. However, they may not encounter the nominative form of rare words, thus some cells of the paradigm will be empty at certain intermediate stages, as schematically illustrated in (107). The availability of the accusative form is worse; children may not hear the accusative form of even very common words, thus there will be more holes in the paradigm cells (cells that are not checked in (107)). The frequency hierarchy of noun stems in (107) (e.g., 1 (person) means that *saram* 'person' is the most common noun stem in Korean) is based on the frequency of noun stems of written Korean from the Sejong corpus.

(107) The schematic shape of Korean noun paradigms for child learners

Frequency hierarchy of noun stems ↓	Unsuffixed	Nominative	Accusative
1 (person)	✓	✓	✓
2 (*time*)	✓	✓	
3 (*work*)	✓	✓	✓
...			
100 (*earth*)	✓	✓	
126 (*head*)	✓	✓	
...	✓		
10,001 (*plum*)	✓		✓
20,003 (*syrup*)	✓	✓	
...			
39,999 (*sardine*)		✓	
43,914 (*anvil*)	✓		
...			

Due to the relative frequency difference between the inflected forms in 'childhood paradigms' as in (107), the reliability of forms becomes very different from the one predicted based on 'adult paradigms' – i.e., all inflected forms of the entire lexicon.

To simulate learning based on 'childhood paradigms', Albright (2008) trained a learning model with data sampled from the full lexicon, based on the frequency of the lexical item and the frequency of the inflection. After 10 different childhood paradigms were generated, the data was fed to Minimal Generalization Learners (Albright and Hayes 2002, 2003) to learn the grammar from the input data. The result was very different from the simulation based on the adult paradigms. For example, the table in (108) compares the scores of rules to predict accusative forms in Korean with and without the token frequency information of the lexicon and the relative frequency of the inflection.

(108) Confidence of mapping rules (Albright 2008:25-27)

	Mean confidence	
	With token frequency	Without token frequency
Unsuffixed →Accusative	.795	.971
Nominative →Accusative	.461	.986

Confidence values are calculated as follows. Consider a hypothetical language having three nominative and accusative pairs [aka] ~ [akol], [apa] ~ [apol], and [ata] ~ [atum]. Learners first construct word-specific morphological rules. For instance, morphological rule [a] → [ol]/ak_ # and [a] → [ol]/ap_#, and [a] → [um]/at_ # for each word is constructed. These word-specific rules are in turn compared, and if a pair of rules share the structural change, learners construct a more general rule by extracting shared structures of the word-specific rules. In this hypothetical example, since the structural change [a] → [ol] is shared from the two forms, [aka] ~ [akol] and [apa] ~ [apol], the generalized rule based on their shared structure is generated; [a] → [ol] / a[+obs, -voi, -spread glottis, -constricted etc]#. The reliability of each rule is determined by dividing the number of forms included in the rules' structural change (hits) into the number of forms included in the rule's structural description (scope). For instance, the structural description 'a[+obs, -voi, -spread glottis, -constricted etc.]#' is met in all three forms, but only two forms [aka] ~ [akol] and [apa] ~ [apol] takes the structural change of the rule, [a] → [ol]. The reliability of this rule is 2/3. Using lower confidence limit statistics (Mikheev 1997), the reliabilities are adjusted. The assumption behind this adjustment is that rules covering many forms are rewarded and those covering few forms are penalized. This adjusted value is called the 'confidence' of the rule.

The confidence of the two mapping rules in (108) are almost tied when the token frequency effect is not considered. Crucially, the unsuffixed form becomes relatively more reliable when token frequency is taken into account. The main reason for this result is that unsuffixed forms are far more frequent than other forms in the paradigms, and especially in child-directed speech the frequency of the unsuffixed nouns is even higher (Lee 1999). The relative frequencies of the three most common inflected forms among nouns from Lee are given in the table (109).

(109) The proportion of inflected forms in child-directed speech

Nouns	
Unsuffixed	75%
Nominative	20%
Accusative	5%

Also, among nouns with high token frequency, stem-final coronal obstruents have very low type frequency; and they are the only targets of phonological neutralization (coda neutralization process in Korean) in the unsuffixed form -- e.g., 47 out of the 1,000 most common nouns (4.7%) vs. 7,097 out of the entire lexicon of Korean noun stems 43,933 (18%). Thus, fewer unsuffixed forms undergo the coda neutralization when common words are considered compared to the lexicon as a whole.

The accusative form becomes even less reliable when child paradigms are considered. The accusative marker has two shapes: *-ɨl* after consonant-final stems and *-lɨl* after the vowel-final stems; also the two liquids [l] and [ɾ] are in allophonic distribution: [ɾ] occurs in intersonorant positions, and [l] elsewhere. Thus, when the stem-final consonant is [l], it takes the accusative marker *-ɨl*, and the [l] becomes [ɾ]. This surface form is the same as a vowel-final stem followed by the accusative marker *–lɨl*. As a result, accusative forms ending in [ɾɨl] are ambiguous as the example in (110) shows, with respect to other inflectional forms in the paradigm. Among the 1,000 most common words[10] out of 43,933 nouns in the Sejong Corpus, 431 (43%) end in vowels, and 114 (11%) end in /l/. As a consequence, 545 (55%) of accusative forms end in [ɾɨl], which is ambiguous.

(110) Ambiguity among accusative forms

/sal-ɨl/ → sar-ɨl 'skin-Acc' /sa-lɨl/ → sa-ɾɨl 'four-Acc'

This result implies that child learners have every reason to believe that the unsuffixed form is the base of Korean noun paradigms: the accuracy of generating other forms from the unsuffixed form is higher than other forms of the paradigm (i.e., phonologically most informative), and it happens to be the most frequent form as well[11].

4.1.2 When the most available form is phonologically not most informative

In the base-selection simulation on the basis of the entire adult corpus of Korean verb paradigms, Albright & Kang (2006) found that the A-suffixed form is the best choice to project other inflected forms as accurately as possible. The table in (111) shows the three types of inflected forms in Korean verb paradigms.

(111) Three types of inflected forms in Korean verb paradigms

Types	Examples	Rule distribution
A-suffixed	-a/-ə 'imperative'	[-a] after stem-final vowel [a, o], [-ə] elsewhere
-ɨ-suffixed	-(-ɨ)myən 'if'	'-ɨ' is present only if the stem ends in a consonant except [l][12]
C-suffixed	-ko 'progressive' –ta 'declarative'	No '-ɨ' insertion even after a stem-final consonant

[10] The decision to consider 1000 most frequent nouns is not based on any principled reason. However, the relative proportions of stem-final vowels and [l] is similar to those in the most frequent 1000 nouns, when several slightly smaller and larger sub-corpora (ranging from 400 most frequent nouns to 2000 most frequent nouns) are considered.

[11] Even without the token frequency information, I believe that there is an extra consideration in favor of the unsuffixed form as the starting point in constructing the paradigm compared to the nominative or the accusative. Given that the unsuffixed form may substitute for the nominative and accusative forms due to case drop, it occurs in a wider range of contexts. If we factor in these syntactic considerations, then perhaps they are enough to scale up the reliability of the unmarked form.

[12] See Kenstowicz and Sohn (2008) for an analysis of the exceptional behavior of stem-final [l] in Korean.

It is not obvious that the A-suffixed form will still predicted to be the most reliable base form if the simulation is conducted based on the data mimicking 'child paradigms'. First of all, the distribution of stem-final verbs among common words raises doubts as to the informativeness of the A-suffixed form in the intermediate learning stages. The table in (112) shows the distribution of the stem-final segments in the A-suffixed form among the most frequent 127 verbs in Sejong Corpus of written Korean. The hierarchy of the stem-final segments is consistent with the one presented in (112) from the corpus involving the 50 most frequent verbs to the full adult corpus.

(112) The distribution of stem-final segments among the most frequent 127 verbs in Korean

Vowels	Liquid	Stops	Clusters	Fricatives	Glides	Nasals	Total
69 (54%)	24 (19%)	20 (16%)	5	4	2	1	127

Crucially, vowel-final stems are systematically over 50% of the data in the corpus composed of the 24 most frequent verbs as well as in the corpus involving the 487 most frequent verbs out of the entire set of 952 verbs. Vowel-final stems undergo various changes including vowel reduction, ɨ elision, and glide formation in the A-suffixed form, as shown in (113). Due to these processes, phonological contrasts of different paradigms are neutralized in the A-suffixed form.

(113) Changes of vowel-initial stems before A-suffixes

	A-suffixed forms	-ɨ-suffixed forms	C-suffixed forms	
e ~ ɑ	hɑ-ɑ → he	hɑ-myən	hɑ-go	'do'
e ~ ə	nurəh-ə → nure	nurə-myən	nurə-k^{h}o	'yellow'
ə ~ ə	sə-ə → sə	sə-myən	sə-go	'stop'
ə ~ ɨ	k^{h}ɨ-ə → k^{h}ə	k^{h}ɨ-myən	k^{h}ɨ-go	'big'
j ~ i	ki-ə → kiə ~ kjə	ki-myən	ki-go	'crawl'
j ~ jə	pjə-ə → pjə	pjə-myən	pjə-go	'spread'

In some vowel-final stem paradigms, glide formation and vowel deletion are optional (Kang 2006).

(114) Variations of vowel-initial stems before A-suffixes

w ~ o	po-a → poa ~ pwa	po-myən	po-go	'watch'
w ~ u	cu-ə → cuə ~ cwə	cu-myən	cu-go	'give'
æ ~ ə	næ-ə → næə ~ næ	næ-myən	næ-go	'take out'

Furthermore, vowel-final stems frequently show lexically-restricted alternations.

(115) Lexically-restricted alternations

a. p^hi-ə → p^hiə ~ p^hjə 'blossom' (glide formation) vs. ki-ə → kiə, *kjə 'crawl' (no glide formation)

b. cu-ə → cwə 'pick up' (glide formation) vs. phu-ə → phə 'scoop' (vowel elision)

The A-suffixed form is the site for other neutralization processes as well, as presented in (116). Since glide-final stems are not frequent among common words, as shown in (112), children may not find a lot of [w] ~ [u] and [w] ~ [p] neutralizations. However, the second type of neutralizations [ɾ] ~ [l] and [ɾ] ~ [t] occur relatively frequently among common words, as the high frequency of liquid-final stems among the common words in (112) indicates. Due to many instances of neutralizations, many A-suffixed forms ending in [ɾ] are ambiguous: they can be either [l] or [t] before the -ɨ-suffixes and the C-suffixes.

(116) Neutralization in A-suffixed forms

	A-suffixed	-ɨ-suffixed	C-suffixed	
w ~ u	sew-ə	seu-myən	seu-go	'build'
w ~ p	tow-a	tou-myən	top-k'o	'help'
ɾ ~ l	saɾ-a	sal-myən	sal-go	'live'
ɾ ~ t	tiɾ-ə	tiɾ-ɨmyən	tit-k'o	'listen'

Some phonological contrasts are neutralized in the C-suffixed form, as in (117). As seen in the table, however, various stop-final words are in this category, which is relatively rare among common words. Thus, when common words are considered, the amount of neutralizations that the C-suffixed form suffers from may not be all that great.

(117) Neutralization in C-suffixed forms

	A-suffixed	-ɨ-suffixed	C-suffixed	
dʒ ~ t	tʃ'idʒ-ə	tʃ'idʒ-ɨmyən	tʃ'it-k'o	'tear'
t^h ~ t	mat^h-a	mat^h-ɨmyən	mat-k'o	'manage'
d ~ t	tad-a	tad-ɨmyən	tat-go	'close'
ɾ~ t	tiɾ-ə	tiɾ-ɨmyən	tit-k'o	'listen'
[ ]~ t	i-e	i-ɨmyən	it-go	'connect'
s~ t	s'is-ə	s'is-ɨmyən	sit-k'o	'wash'

Additionally, the behavior of liquid-final stems adds more uncertainty as to the informativeness of the A-suffixed form, considering 'child paradigms'. The stem-final [l] undergoes intersonorant flapping in the A-suffixed form, as predicted by a general phonotactic principle. However, as observed by Kenstowicz and Sohn (2008), liquid-final verbs omit '-ɨ' in -ɨ-initial suffixes, as if they are vowel-final verbs. As a result, the stem before the ɨ-suffixed form is identical with those in the C-suffixed form, which indicates that the -ɨ-suffixed form and the C-suffixed form can be mutually predictable, while the predictabilities of the -ɨ-suffixed and the C-suffixed form from the A-suffixed form are lower.

(118) Liquid-final verb paradigms

A-suffixed forms	ɨ-suffixed forms	C-suffixed forms	
saɾ-a	sal-myən	sal-da	live'

Kenstowicz and Sohn (2008) also note that [l] is deleted before nasal-initial suffixes within Korean verb paradigms; for example, /sal-nɨn/ becomes [sa-nɨn] 'live-Pres'. Since a consonant is competely absent before a nasal, this results in lowering the reliability of the C-suffixed form. However, this may be less fatal when 'child paradigms' are considered. While liquid-final verbs are the second most frequent among 1000 highest token frequency items, the proportion of nasal-initial suffixes is relatively small among frequent Korean verbal suffixes – i.e., 2 types out of the 25 most frequent verbal suffixes (7,907 of token frequency out of 279,218: 3%), compared to its relatively high proportion in the adult corpus of Korean verbal suffixes (51,745 out of 323,407: 16%). Thus, even though liquid-final verbal stems are relatively frequent among common words, the reliability of the C-suffixed form may not be extremely low in 'child paradigms' due to the small number of nasal-initial suffixes which theoretically decrease the reliability of the C-suffixed form.

In sum, the observation of common verbs make it uncertain that the A-suffixed form is the most reliable choice to construct the paradigms for child learners learning Korean verbs.

4.2 Simulation of a child learner selecting the base form

In order to explore whether the A-suffixed form is still predicted to be the most reliable form despite all of the neutralizations, variations and exceptions, I trained the Minimal Generalization Learner (Albright and Hayes 2002, 2003) based on the 127 most frequent verbs in Korean. The model found the pairwise mappings between the three types of suffixed forms, the A-suffixed form, the -ɨ-suffixed form, and the C-suffixed form, and assessed the accuracy of the mapping rules in each direction using the resulting grammars. The accuracy of the rules are in (119), compared to the results reported in Albright and Kang (2006) where the model was trained on the entire available lexicon of 952 Korean verbs.

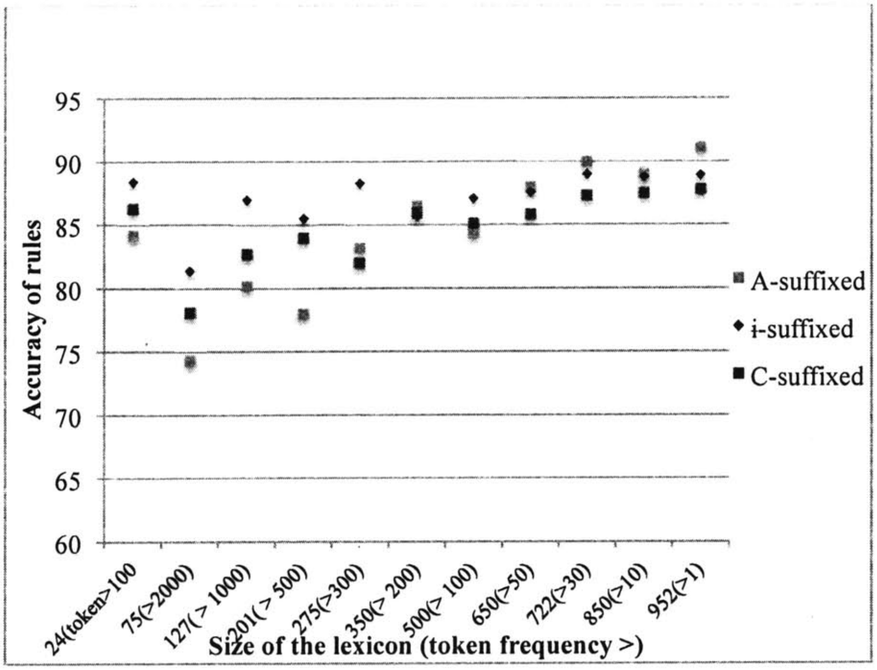
(119) The accuracy of mapping rules among surface forms in most frequent verbs

	Accuracy (the 127 most frequent verbs)	Accuracy (all 952 verbs)
A-suffixed → C-suffixed	84.8%	90.4%
A-suffixed → -ɨ-suffixed	75.6%	91.9%
C-suffixed → A-suffixed	79.2%	86.7%
C-suffixed → -ɨ-suffixed	86.3%	88.9%
-ɨ-suffixed → A-suffixed	88.6%	88.0%
-ɨ-suffixed → C-suffixed	85.5%	91.9%

When the learning is based on the entire lexicon (right side of the table (119)), the A-suffixed form has on average greater accuracy in predicting the other forms (91.1%) than -ɨ-suffixed forms (90.0%) and C-suffixed forms (87.8%). However, the pattern is changed when the learning is on the basis of the frequent words (left side of the table (119)). As shown, the -ɨ-suffixed form has the greatest accuracy on average (87.0%) followed by the C-suffixed form (82.8%). Contrary to the simulation result based on the entire lexicon, the A-suffixed form shows the lowest accuracy (80.2%).

In order to figure out at which acquisition stage the A-suffixed form is predicted to be the most reliable form, additional learning trials were carried out. How many lexical items would learners need to examine in order to predict the most reliable base form as adult speakers do? I gradually increased the size of the lexicon from the 24 most frequent words to the entire lexicon. The learning data for each trial was designed by considering token frequency. For instance, the 24 most frequent words were the ones that have over 10,000 token frequency and the 75 most frequent words have token frequency over 2,000. The graph in (120) shows the average accuracy of the A-suffixed form, the -ɨ-suffixed form, and the C-suffixed form in each learning trail.

(120) The accuracy of mapping rules during the learning



In the very early stage of learning, up to a lexicon size of 201 words, the A-suffixed form has the lowest accuracy, and the -ɨ-suffixed form systematically has the greatest accuracy. In later stages, the most accurate form varies between the -ɨ-suffixed form and the A-suffixed form in different learning trails, but the difference in the accuracy of each form is small. From the learning stage where the size of the lexicon is 650 words out of 952, the A-suffixed form shows the greatest accuracy, but still the competing -ɨ-suffixed form shows high accuracy as well.

Crucially, this result indicates that the A-suffixed form is not the most reliable choice in the early stages of learning. Even after the learners have a larger lexicon, the rate of accuracy difference is too small to be very conclusive about the reliability of the A-suffixed form.

Together with lexical frequency, the relative frequency of the inflection is also important in considering 'child paradigms'. Simply speaking, more frequent parts of the paradigm are more available to children. Is the proportion of the A-suffixes among frequent suffixes large enough to tip learners' decision in favor of the A-suffixed form in early stages of learning? The counts of the 25 most frequent verbal suffixes from Sejong corpus of Korean is given below.

(121) The token frequency of the most frequent 25 out of 1,015 types of Korean verbal suffixes

Suffixes	Count of class	Sum of frequency
C-suffixes	12	138,534
A-suffixes	7	112,282
-ɨ-suffixes	6	31,839

Contrary to the entire lexicon where A-suffixes are most frequent (Albright and Kang 2006), C-suffixes are most frequent in a hypothetical example of 'child paradigms' in (121). The frequency hierarchy is consistent with the table above throughout the subcorpora from the one involving the 5 most frequent suffixes to the 300 most frequent suffixes out of the entire set of suffixes 1,015. Thus, the frequency of A-suffixes in the adult corpus cannot help to boost the reliability of the A-suffixed form.

It has been noted, however, that children produce the A-suffixed form far more frequently than other forms in early stages (Kim and Philips 1998, Lee et al. 2003). Though there is no systematic report about the relative frequency of inflected forms in child-directed speech, conversations between a Korean child and her mother in CHILDES[13] reveals that the majority of inflected verbal forms that the mother speaks to the child are A-suffixed. The data is composed of 12 conversations, each of which was collected on different day, from when the child is 2;0 till she becomes 2;3. The 12 conversations involve 17,303 utterances, from which I found 2,018 verbs; 1,951 from the mother, and 67 from the child. 1,419 out of 1,951 verb tokens produced by the mother were A-suffixed forms, and 52 out of 67 verb tokens produced by the child were A-suffixed forms. These observations suggest that the available token frequency of the A-suffixed form to child learners may be actually far higher in the real learning situation.

To get more reliable frequency information across various parent speakers, I randomly selected ten videos involving child-directed speech in Korean from YouTube. No two of the videos were from the same speaker. Children in the videos were around 10 months-old to 3-years-old. The length of each video was less than 5 minutes (between 1 minute 52 second and 4 minute 55second). The videos involved on average 6 different verbal roots; at least 2 and at most 14. In total, 58 verbal roots were collected across the ten videos.

Two out of the ten videos only showed A-suffixed forms, six videos involved the A-suffixed form and the C-suffixed form, and the remaining two videos have the A-suffixed form, the C-suffixed form as well as the -ɨ-suffixed form. I collected 126 inflected verb tokens. I categorized them into the three suffixed forms as in (109). As shown, the A-suffixed form is the dominant pattern in child-directed speech in Korean, followed by the C-suffixed form. The -ɨ-suffixed form is greatly underrepresented.

[13] http://childes.psy.cmu.edu/browser/index.php?url=EastAsian/Korean/Jiwon/

(122) The proportion of inflected forms

Verbs	
A-suffixed	83 (66%)
C-suffixed	40 (32%)
ɨ-suffixed	3 (2%)

Will this frequency difference be enough for the learners to choose a more frequent, but phonologically a less informative form as the base? In order to test this, another base-selection simulation was conducted, taking lexical frequency and the relative frequency of inflections in child-directed speech in (122) into account.

To create child paradigms, I manipulated the vocabulary size –i.e., total number of lemmas. The experimental results in §2.2 provide us a way of roughly estimating child participants' verbal vocabulary size. To find the lemmas that each child knows for certain, I looked at the list of verbs that the children actually produced in their descriptions of the pictures. The vocabulary size of each child was assessed by looking at how far down the list must be considered in order to include the lemma with the lowest frequency among the ones that each child produced. For instance, one child participant produced verbs from the one that is second most frequent in Korean (*ha-* 'do'; frequency= 79,525) down to the one whose frequency ranking is 425th in the Korean verb list (*nɨlli-* 'lengthen'; frequency =140). This child was assumed to know the 425 most frequent verbs in Korean. This form of estimation yielded 'child lexicons' with vocabulary sizes ranging from 236 to 425 out of the 952 entire verbs.

An alternative method could be pursued to create a 'child lexicon', such as by manipulating the token frequency. Basically, we may estimate what kind of inflected verbs a child might have heard if she was exposed to, for instance, 5,0000 verbal forms. I did not employ this method, since the current experimental results did not provide any clue of estimating how many verb tokens an individual child has heard in her lifetime.

The relative frequency of the inflections was assumed based on observation of the child-directed utterances in (122); the sampler randomly produced 66% of the A-suffixed forms, 32 % of the C-suffixed forms, and 2% of the -ɨ-suffixed forms.

The sampler was fed the entire 952 verbs in the Sejong corpus, and asked to produce inflected verb forms until it produces a form of the lemma with the lowest-frequency. For example, when the vocabulary size was 236, the model produced 156 of the A-suffixed forms (66%), 76 of the C-suffixed form (32%), and 4 of the -ɨ-suffixed form (2%). Due to the relative frequency difference between inflections, the probability of producing the same item in both the A-suffixed form and the C-suffixed form was highest. Relatively few words were produced in both the A-suffixed form and the -ɨ-suffixed form, and the probability of producing the same word in both the C-suffixed form and the -ɨ-suffixed form was the lowest. In this way, a 'child paradigm' was produced. Since the sampler was allowed to generate inflected verbs at random, the generated 'child paradigms' are very different for each learning trial. Thus, I asked the sampler to produce 10 different child paradigms for each 'child lexicon'. Then, Minimal Generalization Learner (Albright and Hayes 2002, 2003) was trained based on these 10 sets of child paradigms. The results of the simulation based on the smallest vocabulary size (the 256 most frequent words) are given in (123), compared to the simulation results based on every inflected forms of the entire lexicon –i.e., 'adult paradigms'.

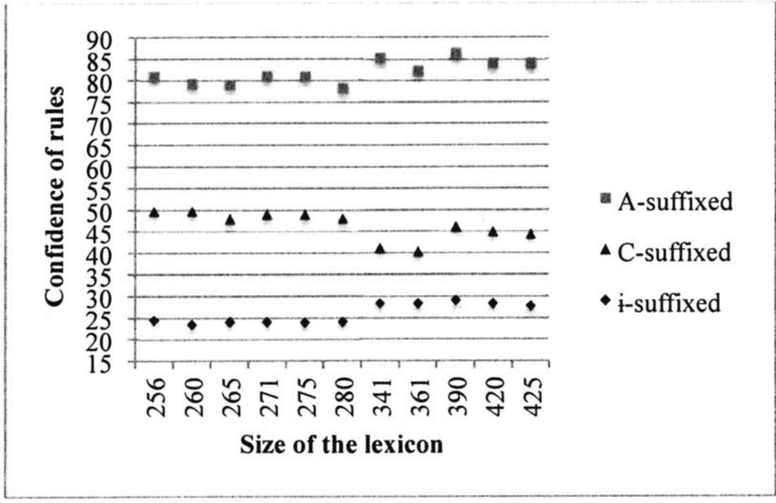
(123) Accuracy of mapping rules in 'child paradigms'

	Accuracy ('child paradigms')	Accuracy ('adult paradigms')
A-suffixed → C-suffixed	83.2%	90.4%
A-suffixed → -ɨ-suffixed	78.6%	91.9%
C-suffixed → A-suffixed	48.2%	86.7%
C-suffixed → -ɨ-suffixed	51.4%	88.9%
-ɨ-suffixed → A-suffixed	22.4%	88.0%
-ɨ-suffixed → C-suffixed	26.6%	91.9%

The ɨ-suffixed form becomes the least reliable form to generate the other forms when child paradigms are considered, while it is the best choice when the learning is based on the entire paradigms. The simulation based on child paradigms breaks the tie among the mapping rules in favor of the A-suffixed form.

The graph in (124) compares the average accuracy of the A-suffixed form, the C-suffixed form, and the -ɨ-suffixed form, when the minimal generalization was trained on learning data which was created based on child lexicons of eleven child participants (4;1 -7;8) in the experiment elicited verbal inflections.

(124) Accuracy of each form in child paradigms



As shown, the A-suffixed form is consistently better than the C-suffixed form and the -ɨ-suffixed forms. This result is the opposite of (119), where the relative frequency of the inflections was not taken into account. Thus, while the A-suffixed form seemed to be phonologically less informative when children have learned only a subset of lexical items, the high frequency of the A-suffix inflection allows the learners to trust that the A-suffixed form is the most reliable choice to construct the grammar that can most accurately generate the other forms in the paradigms.

In addition to the frequency effect, several notable facts, which were found from the videos I collected, seem to boost the reliability of the A-suffixed form even more in early acquisition stages.

First, almost all of the one-verb utterances involve the A-suffixed form, as in the table (125). I included a one-verb sentence with a vocative (e.g., "John, dance!") in counting one-verb utterances. A small amount of the C-suffixed forms was produced as one-verb utterance, and no -ɨ-suffixed form was found at all among one-word utterances.

(125) The proportion of each form in one-word utterances

A-suffixed forms	C-suffixed forms
41(82%)	9 (8%)

As noted by Brent, Murthy, and Lundberg (1995), children acquire items in one-word utterances more readily than the ones in more complex sentence structures, since one-word utterances are salient and no segmentation task is involved in learning the items. The strikingly high frequency of the A-suffixed form within one-word utterances in Korean indicates that children hear more of the A-suffixed forms in salient contexts.

Second, all the A-suffixed forms were found in utterance-final position in the analyzed videos. This pattern is different from the -ɨ-suffixed form and the C-suffixed form. Actually, none of the -ɨ-suffixes in Korean can be used in utterance-final position; they create either subordinate clauses or adjectival clauses. Within the data I collected, 28 out of 40 C-suffixed forms were in utterance-final position and the remaining 12 were in utterance-medial position. Examples of utterance-medial -ɨ-suffixed forms and C-suffixed forms are in (126). Since no parsing task with the following word is involved in detecting the items in utterance-final position, the items will presumably attract more attention than the ones in utterance-medial position.

(126) Utterance-medial -ɨ-suffixed form and C-suffixed form

...məg-imyən dʒul-k'e	eat-if give-Future	*If you eat,* I will give (this to you)!
...p'aŋ *məŋ-nin* Jiwon-i	bread eat-adjectival Jiwon-Nom	Jiwon *who is eating* bread
...*mək-k'o* ka-dʒa	eat-and go-let's	After you eat, let's go

Third, contrary to other forms, the A-suffixed forms were used in a wide variety of contexts such as interrogative, imperative, declarative, exclamation etc. in child-directed speeches. The table in (127) shows the number of meanings that each form expresses from the videos I analyzed. A notable aspect of child-directed speeches is that A-suffixed forms are used in the contexts where other forms could have also denoted the similar meaning. For instance, interrogative forms can be expressed by a C-suffix such as *mək-tʃi?* 'do you eat?', but in child-directed speeches, another interrogative form using a A-suffix *məg-ə?* 'do you eat?' was used for most of the cases.

(127) The number of meanings of each form

A-suffixed forms	-ɨ-suffixed forms	C-suffixed forms
9	1	3

The three meanings of the C-suffixed form were adjectival, interrogative, and connective, and the -ɨ-suffixed form were used in constructing a conditional clause. The usages of the A-suffixed forms found in the videos are given in (128). Using a verbal root *mək-* 'eat', I present examples representing the attested usages. When a form has a broad range of meanings, it is more likely to serve as the base of phonological reanalysis (Kuryłowicz 1947).

(128) The usages of A-suffixed forms

məg-ə!	eat-Imperative	Eat!
məg-ə.	eat-Declarative	I am eating.
mwə məg-ə?	what eat-Integorative	What do you eat?
əmma məg-ə?	mom eat-Interogative	Do you want me(mom) to eat this?
əmma məg-ədo-dje?	mom eat-Cn-can-do	Can I(mom) eat this?
ta məg-ə-n-ne!	all eat-Cn-Past-Exclamation	(Wow), you ate all!
hana məg-ə-t-c'i?	one eat-Cn-Past-Interogative	You (already) ate one, didn't you? (Don't eat any more.)
cal məg-ə-yo!	good eat-Cn-Honorific	How great that you eat so well!
məg-ə-bwa!	eat-Cn-try	Try this!

In sum, observation of child-directed speech reveals that the A-suffixed form is (a) most frequent, (b) predominant in one-word utterances, (c) systematically occurs in utterance-final position, and (d) appears in a wide variety of semantic contexts. All these factors provide good reasons for children to select the A-suffixed form as the most reliable base form to construct other forms of the paradigm. Thus, in spite of the fact that the A-suffixed form is phonologically less informative than other forms for child learners, the reliability of the A-suffixed form increases when the various factors we inspected in this section are taken into account.

5 A biased learner: toward adult stages

Recall that children's phonological preference analyzed in Chapter 3 and Chapter 4 –i.e., inflecting forms faithful to the base form of paradigms. As Chapter 2 showed, children do inflect some items in the correct adult form by productively alternating stem-final segments. The question this chapter pursues is how to predict the attested intermediate learning stages, in which the acquisition of some alternations is mastered, while some others are not.

If OO-IDENT constraints are given an a priori high ranking, children should level all paradigms. Children observed in the current study are not at an initial state, because they do produce alternations for some items. In order to alternate an item, a child must demote the relevant OO-IDENT constraint.

Chapter 4 showed that child learners satisfy OO-IDENT constraints in an *asymmetrical* way: they select one form in the paradigm as the base and inflect other members of the paradigm faithfully to the base form. Can the learning model which has an initial bias toward OO-IDENT constraints and which treats OO-IDENT constraints as an asymmetrical relation correctly predict the observed learning trajectories of Korean noun and verb inflections? I explore this question by means of learning simulations.

5.1 The model: Maximum Entropy Grammar

To model the experimental results, I employed Maximum entropy grammar, which was first adapted in phonology by Goldwater & Johnson (2003). The specific tool I used is the MaxEnt Grammar Tool (MaxEnt; Hayes 2009)[14]. Because this tool is designed mainly to model the learning of an entire grammar at a single time, I manipulated the process of feeding input data in order to model the trajectory of learning. I will first introduce the main mechanisms of this model and then explain how I adapted this tool in the simulation of modeling the learning trajectory.

Just as in the traditional Optimality Theory (Prince and Smolensky 1993, 2004), MaxEnt grammars consist of constraints, which assign violations to candidates, which are evaluated by EVAL. Different from OT, the constraints in a MaxEnt model have numerical weights, and each candidate is assigned a

[14] I do not attempt to explain the mathematics behind maximum entropy grammars. For general background and the application of the Maximum Entropy grammars to learning phonology, see Goldwater and Johnson (2003).

score equal to the sum of its weighted violations. The probability of selecting a given candidate as the output is determined according to the formula in (129).

(129) $p(\omega) = \exp(-\Sigma_i \lambda_{i\chi i}(\omega))/Z$, where $Z = \Sigma_j \exp(-\Sigma_i \lambda_{i\chi i}(\omega_j))$

In formula (129), $p(\omega)$ is the predicted probability of candidate ω; exp(x) is e to the power of x; Σ_i is summation across all constraints; λ_i is weight of the *i*th constraint; χi (ω) is the number of times ω violates the *i*th constraint; Σ_j is summation across candidates (Hayes 2013).

Data is presented to MaxEnt grammar in the form of tableaux of constraint violations. In the file, we provide (a) the input, (b) a set of candidates, with specification of winners (if there are multiple winners, with their frequencies), (c) a set of constraints, and (d) the number of violations of each constraint for each candidate. The program is trained to match the corpus that it is fed. After training, it returns (a) a set of optimal weights for each constraint, and (b) the probability assigned to each candidate based on the optimal constraint weights, which are non-negative real number. If the learning was successful, ideally the model assigns the highest probabilities for the actual winner. For multiple winners, it assigns a probability to each winner that reflects its distributional frequency.

Each constraint is assigned a target weight or a preferred weight, μ, a non-negative real number. The target weights reflect biases that are assumed based on linguistic theory: a constraint is assigned a higher weight if the constraint is given higher priority, absent any data. Note that in this program, it is the absolute value of the weight that determines its relational significance –e.g, a constraint given μ value -20 is considered to have a higher weight than a constraint given μ value -10. Throughout this section, I will report the absolute values of the weights when I mention a μ value. If two constraints are violated an equal number of times, the constraint whose target weight is high ends up in a higher weight, due to the initial bias. Each constraint is assigned a standard deviation a sigma value, σ^2, controlling how much the constraint is willing to diverge from the target weight: a constraint with a lower sigma value is more biased to stick to its target weight.

Different from the strict constraint ranking assumed in the OT grammar, the sum of the trained weights determines the winner; therefore a so-called ganging-up effect may then arise. For instance, consider the hypothetical constraint weighting in (130). Suppose (a) a positional faithfulness constraint for the feature [spread glottis] in prevocalic position (IDENT[±s.g]/_V), (b) a general context-free faithfulness constraint for [spread glottis] (IDENT[±s.g.]), and (c) a markedness constraint banning surface realizations with the feature [spread glottis] (*[+s.g.]). If the constraint ranking of the three constraints are as in the tableau below, *[+s.g.] >> IDENT[±s.g.]/_V >> IDENT[±s.g.] , the candidate [ta] is the winner according to traditional Optimality Theory, because this candidate satisfies the constraint that is highest in this constraint hierarchy. In a MaxEnt grammar using weighted constraints, the sum of the trained weights in the lower positions, IDENT[±s.g.]/_V (weight = 15) and IDENT[±s.g.] (weight = 10), may gang up, and compete with the trained weight of the constraint *[+s.g.] (weight = 20), which is in a higher position. Since the summed weights of IDENT[±s.g.]/_V (weight =15) and IDENT[±s.g.] (weight =10) are greater than the trained weight of *[+s.g.], [t^ha] is predicted to be the winner by the MaxEnt program with these weights. In other words, multiple low-ranked constraints can gang up against a higher ranked constraint.

(130) An example tableau illustrating the gang-up effect in MaxEnt grammar

/t^ha/	*[+s.g.]	IDENT[±s.g.]/_V	IDENT[±s.g.]	
weights	20	15	10	∑
☞a. [t^ha]	*			20
b. [ta]		*	*	25

If the learning is successful, the attested child forms should match the predicted winner. Throughout this section, I present hypothetical weights for constraints that can correctly predict the winner when I present the target grammar that the model is supposed to learn. The specific number assumed to the constraints do not matter, so long as they do not conflict with the hierarchy presented by the hypothetical weights of the constraints.

5.2 Learning phonotactics

Logically, at least some phonotactic patterns must be acquired prior to alternation, since children will not be in a position to learn alternations until they have some lexical items, and they are in a good position to learn phonotactics earlier than that (see Hayes 2004 for the detailed argument). While there is not a lot of empirical evidence for knowledge of phonotactics earlier than alternations, some studies show early acquisition of phonotactics (e.g., Jusczyk et al. 2002), and late acquisition of alternations (e.g., Seidl & Buckley 2005). Given that many of the alternations in Korean paradigms are phonotactically motivated, I assume that children have mastered at least some phonotactic patterns prior to learning alternations. This is modeled by learning constraint weights of Markedness and IO-Faithfulness based on surface forms. The resulting grammar of phonotactic learning serves as the starting point for learning alternations.

5.2.1 Patterns to master

Given that many phonological alternations exist to comply with the phonotactic principles of the language, a child learner starting to figure out phonological alternations will be in a good position, if she has already figured out the phonotactic patterns related to the alternations. In order to model this acquisition stage, I first modeled a subset of Korean phonotactic phenomena that are relevant to the alternations found in noun and verb paradigms. The five relevant phenomena are (a) intersonorant voicing, (b) intervocalic flapping, (c) nasal assimilation, (d) lateralization, and (e) coda neutralization. I will use positional markedness constraints (Steriade 1997, Zoll 1998) to describe phonological contexts in which the constraints apply, but the same result can be captured by employing positional faithfulness constraints (Beckman 1998, Jun 1995).

First, voiceless obstruents /p, t, k/ are voiced [b, d, g] when intersonorant. Therefore [b, d, g] occur only as the voiced allophones of /p, t, k/. By default, the normal state of obstruents is voiceless (*[-son,+voi]). However, voiceless segments are banned when surrounded by sonorant ones (*[+son][-voi][+son]). Faithfulness constraint for voicing (IO-IDENT[±voi]) is ranked low, thus they do not make any difference in Korean; voicing is allophonic. Thus, the ranking of the two markedness constraints, *[-son,+voi] and *[+son][-voi][+son], determines the distribution of voicing. To predict that obstruents are voiced between sonorant segments, *[+son][-voi][+son] should be weighted higher than the summed weights of *[-son,+voi] and IO-IDENT[±voi].

(131) Intersonorant voicing

/ap-a/	*[+son][-voi][+son]	*[-son, +voi]	IO-IDENT([±voi])	
weights	20	10	1	∑
☞[aba]		*	*	11
[apa]	*			20

(132) No voiced obstruent otherwise

/da/	*[+son][-voi][+son]	*[-son, +voi]	IO-IDENT ([±voi])	
weights	20	10	1	∑
☞[ta]			*	1
[da]		*		10

Second, the lateral /l/ is flapped to [ɾ] when intervocalic. [ɾ] occurs only as the intervocalic allophone of [l] (*[+voi][+lat][+voi]), and never in other positions. Thus, by default [ɾ] is disallowed (*[ɾ]). The faithfulness constraint for laterality (IO-IDENT[±lat]) is ranked so low that [ɾ] is allophonic. Thus, the distribution of [l] and [ɾ] is determined by the condition that the weight of *[+voi][+lat][+voi] is higher than the summed weights of *[ɾ] and IO-IDENT([±lat]).

(133) Intersonorant flapping

/al-a/	*[+son][+lat][+son]	*[ɾ]	IO-IDENT([±lat])	
weights	20	10	1	∑
☞[aɾa]		*	*	11
[ala]	*			20

(134) No [ɾ] otherwise

/ɾa/	*[+son][+lat][+son]	*[ɾ]	IO-IDENT ([±lat])	
weights	20	10	1	∑
☞[la]			*	1
[ɾa]		*		10

Third, a non-nasal obstruent followed by a nasal segment is banned (*[-nas, -son][+nas]). These illegal sequences are repaired by nasal assimilation, changing the nasality of the non-nasal obstruent which incurs a violation of IO-IDENT [±nas] is incurred. To predict nasal assimilation, IO-IDENT[±nas] needs to be weighted less than *[-nas, -son][+nas]. Vowel epenthesis is also a logically possible repair, which is observed between a verbal root and certain inflectional suffixes. Except for verb inflection, vowel epenthesis never occurs in the language. Thus, the faithfulness constraint barring vowel epenthesis should be weighted higher than IO-IDENT[±nas], in order to predict nasal assimilation, not vowel epenthesis. The epenthetic vowel in Korean is [ɨ], thus the relevant faithfulness constraint banning vowel epenthesis is IO-DEP ɨ. By employing a faithfulness constraint which maintains nasality in the input-to-output mapping before a non-lateral segment (IO-IDENT[+nas]/_[-lat]), we can capture why obstruents should become nasals when adjacent to a nasal segment, rather than nasals becoming obstruents.

(135) Regressive nasal assimilation

/apmi/	*[-nas,-son][+nas]	IO-DEP ɨ	IO-Ident [+nas]/_[-lat]	IO-Ident [±nas]	IO-Ident [±voi]	
weights	30	30	3	3	1	∑
☞ammi				*	*	4
apmi	*					30
appi			*	*	*	7
abɨmi		*			*	31

Fourth, a lateral that precedes [n] is illegal (*[+lat][+nas,-lab]), and the following nasal undergoes lateralization. Thus the weight of IO-IDENT[±nas] should be lower than the weight of *[+lat][+nas,-lab].

Vowel epenthesis is not the attested repair of this illegal sequence either; IO-DEP ɨ must outrank IO-IDENT[±nas] . In order to avoid nasalization, such as /ln/ → [nn], I employ a faithfulness constraint requiring that laterality in the input should be realized in the output (IO-MAX[+lat]). While the /ln/ → [nn] mapping violates the constraint IO-MAX[+lat] as well as IO- IDENT[±nas], the mapping /ln/ → [ll] violates only the latter constraint.

(136) Lateralization

/alni/	*[+lat][+nas, -lab]	IO-DEP ɨ	IO-IDENT[±nas]	IO-MAX[+lat]	
weights	30	30	3	2	Σ
☞alli			*		3
anni			*	*	5
alni	*				20
aɾɨni		*		*	32

Last, the three-way laryngeal contrast and three-way manner contrast in obstruents is neutralized to its homorganic voiceless lenis stop member in coda position, and is faithfully realized elsewhere; /p, p', p^h/ is neutralized to [p], /k, k', k^h/ to [k], and /t, t^h, s, s', tʃ, tʃ^h/ to [t] in coda position. Consider the behavior of aspirated stops as an example. Spread glottis is disfavored in coda position (*[+s.g.]#). I also assume a general markedness constraint for spread glottis (*[+s.g]). In general, the feature spread glottis surfaces in the outputs: a faithfulness constraint for spread glottis (IO-IDENT[±s.g.]) is weighted higher than *[+s.g.]. Aspirated stops are neutralized when they appear in coda position; the constraint IO-IDENT[±s.g.]) has a lower weight than the summed weights of *[+s.g.]# and *[+s.g.].

(137) Faithful realization of laryngeal features

/p^ha/	IO-IDENT([±s.g.])	*[+s.g.]	
weights	10	5	Σ
☞[p^ha]		*	5
[pa]	*		10

(138) Coda neutralization

/ap^h/	IO-IDENT([±s.g.])	*[+s.g.]#	*[+s.g.]	
weights	10	8	5	Σ
☞[ap]	*			10
[ap^h]		*	*	13

In an analogous way, the neutralization of /s, tʃ, t^h, tʃ^h/ into [t] in the coda position and their faithful realizations elsewhere is analyzed as follows. Markedness constraints banning the features strident

(*[+strid]#, *[+strid]), continuant (*[+contin]#, *[+contin]), and delayed release (*[+delayed release]#, *[+delayed release]) are assumed. IO-IDENT constraints for each feature are needed as well. The weighting relation between the faithfulness constraint and the two markedness constraints for each feature is the same as that presented for the feature spread glottis in (137) and (138): a faithfulness constraint is ranked over a general markedness constraint, but it is weighted less than the sum of the general markedness constraint and the positional markedness constraint specific to coda position. The tense or glottalized non-coronal obstruents /p'/ and /k'/ are neutralized into [p] and [k] in coda position and otherwise faithfully realized. For describing this pattern, a markedness constraint which disfavors constricted glottis (*[+c.g.]# , *[+c.g.]) and a faithfulness constraint for this feature (IO-IDENT[c.g.]) are assumed and the weight relation is the same as those presented in (137) and (138).

The last phonotactic pattern is palatalization: coronal obstruents are palatalized before high front vocoids: alveolar fricatives [s, s'] become their palato-alveolar counterparts [ʃ, ʃ'] in the palatalization context. A markedness constraint barring alveolar fricatives followed by high front vocoids (*[+anterior, +cont, +strid][-cons, +high, -back]) is employed. A faithfulness constraint for the feature anterior (IO-IDENT[±anterior]) is weighted lower than the markedness constraint.

(139) Palatalization

/si/	*[+anterior, +cont, +strid][-cons, +high, -back]	IO-IDENT([±anterior])	
weights	15	5	∑
☞[ʃi]		*	5
[si]	*		15

5.2.2 Input data representing partial phonotactic knowledge

This study is interested in the phonotactic knowledge of young learners who have just started to uncover patterns of alternation in their language. How extensive is primary language input at such an acquisition stage? Child learners definitely have heard nouns as well as verbs (and possibly other forms such as adverbs as well). Intuitively, however, the forms that they have been exposed to must be sparse; they may not have encountered all the inflected forms of every noun or verb in their language. In early acquisition stages, it is likely that children learn patterns of phonotactics mostly from common words and from frequent parts of the paradigm. For instance, it is very unlikely that Korean children have acquired intervocalic flapping from an honorific declarative form found exclusively in written Korean *–ɨrjəmnida* attached to an uncommon word for child listeners such as *həl-* 'demolish' –e.g., /həl-ɨrjəmnida/ → [hərɨrjəmnida]. Instead, they are likely to discover the pattern of intervocalic flapping from a casual declarative form of a common verb such as /mal-a/ → [maɾa] 'roll'. Based on this intuition, I simulated phonotactic learning with input data that could potentially represent a young learner's lexicon.

The learning data was composed of nouns and verbs. The goal was to generate a 'childhood lexicon' which is composed of more of common words and more frequent parts of the paradigm. The entire noun and verb lexicon of Korean, 43,932 noun stems and 952 verb stems, was taken from the Sejong corpus of written Korean. A file was created to include unsuffixed, nominative, and accusative forms of all 43,932 noun stems, and the A-suffixed, -ɨ-suffixed, and C-suffixed form of all 952 verb stems. To generate the 'childhood lexicon', I borrowed a program from Albright (2008), which produces common words more often than uncommon words, and frequent parts of the paradigm more often than infrequent parts. The model randomly selected inflected nouns and verbs, in Monte Carlo fashion according to their lexical frequencies and the relative frequencies of their inflections. The probability of selecting an inflected form is determined by the probability of choosing the lemma of the form multiplied by the probability of the inflectional affix.

The model was asked to produce inflected forms according to the proportion of each inflection from child-directed speech, which was reported in the preceding chapter. The proportion of inflections is repeated in (140). For instance, when the model produces 1,000 inflected verb forms, 660 of them are A-suffixed forms (66%), 320 are C-suffixed forms (32%), and 20 are -ɨ-suffixed forms (2%).

(140) Proportion of inflections

Nouns	
Unsuffixed	75%
Nominative	20%
Accusative	5%

Verbs	
A-suffixed	66%
C-suffixed	32%
ɨ-suffixed	2%

I asked the model to produce 1,000 tokens of Korean nouns and 1,000 tokens of Korean verbs. Since the model randomly picked items, chances are high that the shape of each 'child lexicon' is very different for different learning trials. Thus, it was asked to produce 5 different child lexicons that consist of 1,000 tokens of Korean nouns and 10 different child lexicons composed of 1,000 tokens of Korean verbs. Verb lexicons were generated with twice as many tokens as nouns, following the finding that Korean children are exposed more to verbs than to nouns in early acquisition stages (Choi 2000). In total, 5,000 nouns and 10,000 verbs were generated and they were used as the input data for simulating the early stage learning of phonotactics.

The model sometimes produced duplicate tokens –i.e., the same inflectional form of the same word, especially with unsuffixed noun forms of highly frequent lexical items and A-suffixed verb forms also of highly frequent lexical items. This was the predicted outcome, since the model was asked to produce common inflected forms of common words more to mimic the shape of child lexicon. I simulated the amount of duplication by assigning the frequency of duplication to the winning candidates. For instance, the unsuffixed form of the most frequent noun stem *saram* 'man' was generated 14 times among the entire 5,000 nouns generated by the program (Albright 2008), so I provided the unsuffixed form of the noun stem *saram* 'man' with the frequency of 14. If no duplicated token was generated for an inflected form of a certain item (that is, if the model generated only one token of a form), the frequency of that form was assumed 1. Loser candidates which compete with the winner were assigned zero frequency.

Training data was given in the form of tableaux with candidates, constraint violations, and the frequency of the winners. The initial trial was positive-evidence-only learning with an equal target weights for all markedness constraints and an equal target weights for all faithfulness constraints. I will shortly show where this failed, and how the setting of the learning model was modified. As competing candidates, I provided (a) all possible combinations of voicing and aspiration in all positions, taken from a Pseudo-Korean simulation by Hayes (2004, p.18), (b) [l] and [ɾ] in morpheme initial, intervocalic and morpheme final positions, (c) nasal preceding and following an obstruent, (d) a lateral preceding and following a nasal, and (e) a coronal obstruent [s, $tʃ^h$, t, tʃ, t^h] in morpheme initial, intervocalic and morpheme final positions.

The Markedness and IO-IDENT constraints introduced in this section were fed into the model. The absolute value of the target weight of Markedness constraints (weight= 20) was assumed to be higher than that of the Faithfulness constraints (weight = 10). This constraint ranking corresponds to the very initial state of phonological acquisition, namely an infant is able to produce only unmarked structures. I assumed the same σ^2 value for all constraints (σ^2=1,000), since there was no particular empirical reason for letting the sigma value vary.

5.2.3 The results of phonotactic learning

Positive-evidence-only learning was successful except for one failure; the model incorrectly predicted that aspirated, tensed, continuant and strident obstruents should be neutralized into their homorganic lenis counterparts in prevocalic position, such as / t^ha / → *[ta], or / $tʃ^h$a / → *[tʃa], where faithful realizations are expected. To solve this problem, the weight of the markedness constraints was lowered from 20 to 15, for instance (e.g., lower target ranking of *[+s.g.] and *[+s.g.]#). However, this created another unwanted outcome; aspirated stops in coda position were not neutralized, so the learning model incorrectly predict /at^h/ → *[at^h] and /$atʃ^h$/ →*[$atʃ^h$]. The same was true for other coronal obstruents. This failure is due to the ganging-up effect of the general markedness constraint and the faithfulness constraint

– e.g., *[+s.g.] and IO-IDENT[±s.g.]. The sum of the two constraints becomes larger than the weight of the positional markedness constraint such as *[+s.g.]#, as shown in (141).

(141) Constraint weights which fail to describe the realization of / t^h /--e.g., / at^h / → [at^h], /t^ha/ → [t^h a]

Constraint	Target weight	Post-learning weight
*[+s.g.]	20	26.06
IO-IDENT[±s.g.]	10	7.88
Sum of the weights		= 34.94
		V
*[+s.g.] #	20	32.74

I borrowed an idea *Favor Specificity* from Hayes (2004:22), in order to solve this phonotactic learning problem. Hayes's argument for *Favor Specificity* is based on conservatism: if a specific constraint suffices, a general constraint is not needed to rule out rival candidates. The problem laid out in the previous paragraph can be understood as an overgeneralization problem caused by the extra weight excessively added by a general markedness constraint: the constraint weights either overgeneralize the faithful realization of /t^h/ or it overgeneralizes the neutralization of /t^h/ across different phonological contexts due to the high trained weight of *[+s.g.]. The violation of a general constraint will be the subset of a specific one with which it shares the structural description (Koutsoudas, Sanders, and Noll 1974). If we allow the specific constraint alone to describe the phonotactic patterns, and rank the general constraint low enough so as to not play any significant role in predicting winners, the grammar can predict the correct patterns. Based on this idea, the target weight of the general markedness constraints was adjusted. Recall that the target weight of all faithfulness constraints was 10 and that of all markedness constraint was 20 in the previous learning simulation. This time, faithfulness constraints were again given 10 as their target weights, but the target weight of general markedness constraints were assumed to be 13 and that of specific markedness constraints were assumed to be 20. The sigma value was same as the previous simulation –i.e., σ^2=1,000. As before, the training set provided only positive evidence.

After training, the model was checked as to how well it learned the subset of Korean phonotactics. To test the result of learning Korean phonotactics, I gave the model some underlying forms that were not fed as original input data; these forms were selected from among the ones that were not found in the 'childhood lexicon'. Some underlying forms were given as phonotactically legal forms and some were given as illegal forms in Korean. Illegal inputs are bold-faced in the table (142), where I simplified the testing items as aC (representing nouns starting with a vowel followed by a consonant), Ca (with a consonant followed by a vowel), aCa (with a vowel followed by a consonant and a vowel), and aCCa (with a consonant cluster between two vowels) forms. If the learning was successful, the model is expected to predict legal outputs regardless of the legality of the inputs. To illustrate the result, I present the winners to which the model assigned the highest probabilities among candidates.

(142) The result of phonotactic training

Voicing	In	Out	Flapping	In	Out	Nasal	In	Out	Lateral	In	Out
	/ad/	[at]		/aɾ/	[al]		/apna/	[amna]		/alna/	[alla]
	/da/	[ta]		/ɾa/	[la]		/akna/	[aŋna]		/alma/	[alma]
	/ata/	[ada]		/ala/	[aɾa]		/atna/	[anna]			

Coda neutralization	In	Out	In	Out	In	Out	In	Out
	/at^h/	[at]	/as/	[at]	/atʃ^h/	[at]	/atʃ/	[at]
	/t^{h}a/	[t^{h}a]	/sa/	[sa]	/tʃ^{h}a/	[tʃ^{h}a]	/tʃa/	[tʃa]
	/at^{h}a/	[at^{h}a]	/asa/	[asa]	/atʃ^{h}a/	[atʃ^{h}a]	/atʃa/	[atʃa]

The trained grammar predicted the correct outputs when it was given illegal inputs. It also faithfully mapped correct inputs to the outputs with the highest probabilities. Thus, I assume that the model now has knowledge of the subset of Korean phonotactics that are relevant to learn alternations –i.e., the model is ready to learn alternations.

5.3 Learning alternations from Korean nouns

5.3.1 Attested learning trajectory

Considering the children's alternation patterns reported in Chapter 2, the learning stages which a model must traverse are as follows.

First, the model completes the learning of very frequent alternations in the language. Those are are motivated by markedness constraints that are also obeyed in monomorphemic words, as the mastery of those alternations by the youngest child participants showed. Specifically, it must learn intersonorant flapping, coda neutralization, and intersonorant voicing of noncoronal obstruent-final nouns, such as /p/ ~ [b] and /k/ ~ [g]. Recall that, at this learning stage, children 'wrongly' alternated coronal obstruent-final nouns ending in /s, t^h, tʃ, tʃ^h/ with [d] before all nominal suffixes. /s, t^h, tʃ, tʃ^h/ ~ [d] alternations are relatively less frequent than the patterns of alternations acquired in earlier stages; instead, stem-final coronal obstruents of nouns are generally in variation with [s]. Especially before the nominative suffix [-i], the surface form [d-i] does not conform to phonotactics: [d-i] violates the derived-environment palatalization processes in Korean. If the model goes through the same learning stages as children, we expect that it first incorrectly predicts coronal obstruent-final nouns to surface as [d] throughout all suffixed forms.

When the model undergoes additional training, it must stop producing any phonologically or morphologically ill-formed forms, since all child participants in the next acquisition stage produced phonotactically legal forms. However, children's production showed morphological or lexical deviation from adults in inflecting coronal obstruent-final nouns; they produced forms without optional case markers, with alternative suffixes, and as nominal compounds, or they completely avoided alternations by selecting non-alternating lexical items. Crucially, all of the attested forms of coronal obstruent-final nouns show the use of the stem found in the base form: the stem ending in [t] or [d] as the result of intersonorant voicing when surrounded by sonorant segments. Thus, we expect that the legal but deviant forms that are faithful to the base form arise at this intermediate learning stage.

The experimental results tell us that children's inflection pattern for aspirated noncoronal obstruent-final nouns was consistent throughout the very early and intermediate age groups. As shown in section 2.1, underlying stem-final /p^h/ and /k^h/ in Korean noun paradigms can be realized either faithfully as [p^h] and [k^h] or as their neutralized counterparts [p] and [k]. While adult participants preferred to realize the underlying aspiration value, children almost always neutralized aspirated /p^h/ and /k^h/ to [p] and [k]. Thus the model is expected to predict more of neutralized surface forms in intermediate stages, before it figures out the preference of faithful realization of underlying aspiration.

More training will provide the model with sufficient evidence to not predict morphologically or lexically deviant forms of coronal obstruent-final nouns. Rather, it is expected to predict [t] ~ [s] alternations before nominative suffixes. Given that [s] is one of the five attested variants of coronal obstruent-final nouns from adults, the expectation is as follows: the variant [s] should emerge as the predominant form in the intermediate stage before other variants are predicted. At the same stage, we expect more faithful realization of /p^h/ and /k^h/ than in earlier stages, as we observed from older children.

The expected learning order of alternations is summarized in (143). I mark case deletion as a representative of morphological and lexical deviations in the table below.

(143) The expected order of alternations

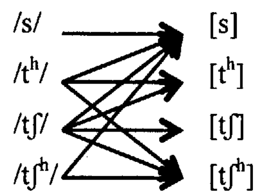
Lateral alternation, Voicing altenration	/aɫ-i/ → [aɾi], /ap-i/ →[abɨl], /ak-i/ → [agi]
Coda neutraliztaion	/as,at^h, atʃ, atʃ^h/ → [at]
	/ap^h/ → [ap], /ak/ →[ak]
Possibility of neutralizing aspiration before V, Voicing alternation	/ ap^h-i/ → [abi], /ak^h-i/ →[agi]

Derived-environment palatalization	/as,at^h, atʃ, atʃ^h-i/ → *[adi]
Various morphological and lexical deviations	/as,at^h, atʃ, atʃ^h-i/ → [at]

Coronal obstruent-final nouns' alternation to [s]	/as,at^h, atʃ, atʃ^h-i/ → [aʃi]
Less frequent neutralization of aspiration before V	/ap^h-i/ → [abi] ~ [ap^h-i], /ak^h-i/ →[agi] ~ [ak^h-i]

The learning tasks for the model are not trivial for several reasons. First of all, the alternation pattern /as,at^h, atʃ, atʃ^h-i/ → *[adi], which the model never finds in the input data, must emerge at an early stage. Given that stem-final /s, t^h, tʃ, tʃ^h/ are neutralized to [t] in the isolation form (i.e., the base form), the alternations involve voicing alternations between the base form and the inflected forms. The model will predict [d] as the surface realization of coronal obstruent-final nouns, if it figures out that many pairs of the base and the inflected forms in the paradigms exhibit voicing alternations before it generalizes other patterns of alternation; as a consequence the grammar first generalizes the voicing alternations to the inflection of coronal obstruent-final nouns whose base forms end in [t]. In other words, it needs to find the shared structure (voicing alternations) of various segmental alternations, and over-regularize the pattern to [t]-final nouns, as young children did in the experiment. Second, the model must quickly learn coda neutralization, so that it initially predicts the relation between, for instance, /ap^h-i/ → [abi]. As shown in Chapter 2, however, the frequency of stem-final noncoronal aspirated obstruents is extremely low in Korean (see the table (64)). Thus, in order to predict the /ap^h-i/ → [abi] alternation in early stages, the model needs to find enough evidence of coda neutralization from other stem-final segments' alternations, such as /atʃ^h/ → [at] or /at^h/ → [at]. Third, various stem-final coronal obstruents, such as /s, t^h, tʃ, tʃ^h/, need to surface predominantly as [s] at the early stages before the surface realizations such as [t^h], [tʃ], and [tʃ^h] are predicted. The attested input-to-output mappings in adult Korean are sketched in (144) (the data in (144) is collected from Kim 2003, Choi 2004, Kang et al. 2004, and Jun 2010). As shown, all stem-final coronal obstruents are in variation with [s], but some of them are in variation with [tʃ^{h}] and [t^{h}] as well. Thus, the question is how the model can consider that only [s] is the reliable choice at the early stage of learning, in spite of other possibilities such as [tʃ^{h}] and [t^{h}].

(144) Input-to-output mappings of stem-final coronal obstruents



To simulate this learning trajectory, I pursue a learning hypothesis that is assumed in the Gradual Learning Algorithm (Boersma 1997, Magri 2012) and Maximum Entropy Grammar (Goldwater and Smith 2003): the rate of demotion and promotion of constraints is determined by the frequency of their violations in the input. If we assume the initial high ranking of OO-Ident constraints, and if the model treats the OO-Ident constraints as an asymmetrical relation (i.e., corresponding segments in surface inflected forms and the base form agree in their features), can it successfully predict the learning trajectory laid out in (143)?

5.3.2 The target grammar

To model the learning trajectory of Korean noun paradigms, five types of constraints below are necessary. I will show why we need each type of constraint in turn.

(145) Four types of constraints that are implemented

Types of constraints	Examples
a. OO-IDENT constraints	OO-IDENT([Strid]): Corresponding segments in the base and output agree in stridency.
b. Anticorrespondence constraints	t →s / _-INFL: If the base form (the isolation form) ends in [t], its corresponding stem must end in [s].
c. IO-IDENT constraints	IO-IDENT([Strid]): Corresponding segments in the input and output agree in stridency.
d. Markedness constraints	*[+s.g.]: Spread glottis in surface realization is dispreferred.
e. Expressiveness, Economy	Expressiveness Morphemes in the output have their corresponding morphemes in the input.

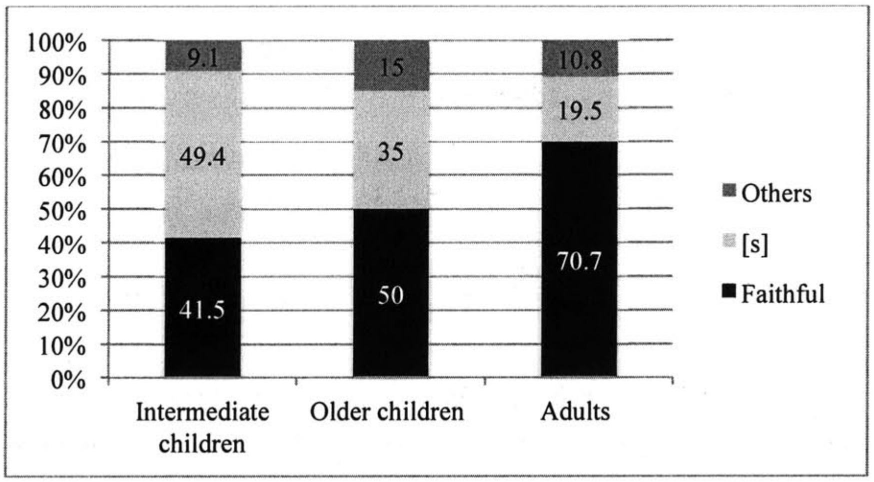
OO-IDENT constraints play a crucial role in predicting the inflectional patterns of coronal obstruent-final noun stems produced at the very early acquisition stages; the youngest children in the experiments never alternated stem-final coronal obstruent [t] with [s], but they always alternated [t] with [d]. Their choice involves the alternation of the voicing feature 1from the stem-final [t] in the base form. Without assuming initially highly ranked OO-IDENT constraints, nothing would favor the outputs that children in this stage actually prefer, namely the [t] ~ [d] alternation.

To predict the alternation of stem-final [t] with [d] before vowel-initial suffixes in the earlier stages, the OO-IDENT constraint for the feature voicing must be quickly demoted below the Markedness constraint banning the realization of voiceless obstruents when intersonorant. This pattern seems to be predictable in the early stages of the modeling, given that the most frequent alternation among obstruent-final nouns in the Korean noun paradigm is the voicing alternation, such as [t] ~ [d], [p] ~ [b] and [k] ~ [g] (Jun 2010).

Children in the early stage did not produce forms involving other alternations [t] ~ [dʒ], [t] ~ [t^h], [t] ~ [$tʃ^h$], and [t] ~ [s]. To block such alternations, OO-IDENT constraints for the features stridency (OO- IDENT [±STRID]), continuancy (OO- IDENT [±CONTIN]), spread glottis (OO- IDENT [±s.g.]) and delayed release (OO- IDENT [±d.r.]) must be initially ranked high.

The observed learning trajectory, however, cannot be accounted for using only the constraints describing the relation between outputs, namely OO-IDENT constraints. From children in the intermediate and in the oldest groups, we observed that all underlying coronal obstruent segments /s, tʃ, $tʃ^h$, t^h/ predominantly alternated with [s], and the instances of faithful realizations of underlying segments were less frequent compared to the results of adults. The graphs below compare the proportion of faithful realization of coronal obstruent-final noun stems –e.g., /at^h-e/ → [at^{h}e], unfaithful mapping to [s] –e.g., /at^h-e/→ [ase], and unfaithful mappings other than [s] –e.g /at^h-e/ →[atʃ^{h}e], between the three age groups who participated in the single-picture description experiment in section 2.1. The results of /s/-final nouns are excluded here, since it is not clear whether speakers realized [s] because its underlying form is /s/ or because they prefer [s] in surface realizations. The result of the youngest child group is not illustrated here, since they always alternated every coronal obstruent-final noun with [d]-final surface forms.

(146) The percentage of allomorphs of stem-final coronal obstruents



Can the model predict the learning trajectories illustrated in (146) in terms of OO-IDENT constraints? The model might be able to predict the overall predominant [s] realizations of stem-final coronal obstruents; to succeed in this learning task, the grammar must extract the stridency portion of the alternation found in the base-final [t] to variant-final [tʃ] and [t] to [tʃ^h] and derive the [t] to [s] alternation in some intermediate stages of learning. In this way, we expect that stem-final [s] is predicted more often than what is found in the adult language, matching what we observed from child learners.

To describe frequent occurrences of [s], we may assume that children accidentally have underlying /s/ for all stems. However, this is not enough because there is a difference between true /s/ and others: every /s/-final stem was always realized as [s] while other stem-final segments were sometimes realized as [s]. What if children's tendency to have underlying /s/ is probabilistic? In other words, what if children are always likely to have /s/ for true /s/, whereas for other forms, they are sometimes getting real data and sometimes inferring /s/? This is not enough either, since on the individual child level, we cannot assume that they have simply inferred /s/ for some fraction of the coronal nouns.

Also, there is no way that the model with our OO-IDENT constraints can favor stem-final [s] from the base-final [t] whose underlying value is /t^h/. The experimental results showed that this pattern of alternation was indeed frequently produced by adults. The attestation of /t^h/ to [s] alternation indicates that we need anticorrespondence constraints as in (147) to (150), which require that prevocalic allomorphs of nouns should end specifically in [s] from all underlying forms, if their corresponding isolation forms end in [t] (Kang 2003, Davis & Kang 2006, Jun 2010).

(147) t → s/ _-INFL : If an isolation form ends in [t], its corresponding inflected form must end in [s].
(148) t → t^h/ _- INFL: ..., its corresponding inflected form must end in [t^h].
(149) t → $tʃ^h$/ _- INFL: ..., its corresponding inflected form must end in [$tʃ^h$].
(150) t → dʒ/ _- INFL: ..., its corresponding inflected form must end in [dʒ].

At the early stages, the OO-IDENT constraint for [STRIDENT] must rank above t →s /_-INFL, so that the model does not predict [s] as a surface realization of inflected forms for coronal obstruent-final nouns, as observed from children in the youngest and intermediate groups. At the later stages, OO-IDENT for [STRIDENT] must be demoted below t →s /_-INFL, so that it predicts [s], as found from children in the oldest group. I assume a lower target weight for output-to-output anticorrespondence constraints than for OO-IDENT constraints based on a principled reason – since specific segmental relations between surface forms are found restrictively within inflectional paradigms, the reliabilities of such constraints may be lower than OO-IDENT constraints which are relevant to the processes found in other paradigms as well.

As shown in (144), the surface realizations of coronal obstruent-final nouns differ depending on their underlying forms. I encode the relation of underlying forms and inflected forms in the grammar by employing IO-IDENT constraints for stridency (IO- IDENT [±STRID]), continuancy (IO- IDENT [±CONTIN]), spread glottis (IO- IDENT [±s.g.] and delayed release (IO- IDENT [±d.r.]).

We can capture some crucial aspects of the attested input-to-output mappings, if the interplay of IO-IDENT constraints and output-to-output anticorrespondence (OO-anticorrespondence) constraints in (147) to (150) is assumed[15]. As presented, /s/ and /tʃ/ are realized as [s] more than /t^h/ is. If there is a ganging-up effect of IO-Ident constraints and OO-anticorrespondence constraints, such as the IO-IDENT constraint for

[15] While the current implementation of constraints have many benefits in describing the observed alternations patterns described in this section, I should admit that the grammar assuming IO-IDENT constraints and output-to-output anticorrespondence constraints, and the ganging-up effect of the two types of constraints has a minor problem. The experimental results showed that /$tʃ^h$/ alternated to [s] as infrequently as /t^h/ alternated to [s], as presented. Because the /$tʃ^h$/ to [s] alternation satisfies both the IO-Ident constraint for [STRIDENT] and output-to-output anticorrespondence constraint t →s /_-INFL, theoretically /$tʃ^h$/ must surface as [s] more frequently than /t^h/ does if the weights of IO-Ident constraints for [STRID] and t →s /_-INFL gang up. Thus, if we assume IO-IDENT constraints, instead of input-to-output anticorrespondence constraints, there is a chance that it may overpredict /$tʃ^h$/ to [s].

[STRIDENT] and the anticorrespondence constraint t →s /_-INFL, the realization of [s] can be predicted more from /s/ and /tʃ/ than from /tʰ/; /s, tʃ/ to [s] satisfies both the IO-Ident constraint for [STRIDENT] and the anticorrespondence constraint t →s /_-INFL, while /tʰ/ → [s] satisfies only the anticorrespondence constraint t →s /_-INFL.

The model also assumes IO-CORR constraints which penalize morpheme insertion. One such markedness constraint is IO-DEPMORPHEME as in (151), which bans morpheme insertion where a simpler form would have been otherwise adequate. It is possible to assume other morphologically deviant forms as well, such as forms which lack morphemes expressed in adult-like morphological structure. One could simulate such data by implementing additional constraints such as a constraint banning morpheme deletion—i.e., IO-MAXMORPH for describing the deletion of a case marker. The role of those additional constraints will be the same as the role of the constraint IO-DEPMORPH, in that they penalize deviant forms that were observed in the intermediate stages.

(151) IO-DEPMORPH: Morphemes in the output have their corresponding morphemes in the input.

Children in the youngest group never produced such deviant forms, and it is only at the intermediate stages that the deviant forms were observed. This fact indicates that the ranking of the markedness constraints should be high in the earlier stage and then it should be lower in the intermediate stage. This implies that younger children are less likely to produce morphologically complex or long forms than children in the intermediate stages. The current experimental data do not tell whether it is younger children's preference to not to produce longer forms, or their ignorance of such forms[16]. In the current modeling, I assume all outputs that are attested in all developmental stages as candidates in every simulation stage, and explore whether the model correctly selects the attested forms along the learning trajectory.

The markedness constraints in (145) refer to dispreferred surface structures, such as spread glottis in general or specifically in coda position (*[+s.g.], *[+s.g.]#). All of the markedness constraints that are introduced in the simulation of the phonotactic learning stage belong to this category of constraints. In addition to these, I include a markedness constraint describing morphologically conditioned palatalization in Korean. Recall that alveolar stops [t, tʰ] becomes palato-alveolar affricates [tʃ, tʃʰ] before high front vocoids when a morpheme boundary intervenes. A markedness constraint barring high front vocoids after

[16] This raises a crucial empirical issue: can children in the youngest group understand or produce morphologically complex forms such as nominal compounds? If they do not know complex forms yet (either they cannot produce or they cannot understand complex forms), younger children cannot generate such forms as potential candidates, thus Markedness constraints such as *IO-DEPMORPH do not play any role in determining the outputs at this stage.

the morpheme ending in alveolar stops is employed (*[+anterior, -cont, -strid]#[-cons, +high, -back]). This constraint must outrank the faithfulness constraint for the feature anterior.

The model also assumes EXPRESSIVENESS and ECONOMY constraints, which are introduced in Chapter 3, in order to predict morphologically deviant forms.

Children in the youngest group never produced morphologically deviant forms, and it is only at the intermediate stages that such forms were observed. This fact indicates that the ranking of the Economy constraints must be high in the earlier stages and then it must be lower in the intermediate stage. This implies that younger children are less likely to produce morphologically complex or long forms than children in the intermediate stages. The current experimental data do not tell whether it is younger children's preference to not to produce longer forms, or their ignorance of such forms[17]. In the current modeling, I assume all outputs that are attested in all developmental stages as candidates in every simulation stage, and explore whether the model correctly selects the attested forms along the learning trajectory.

To summarize, it is crucial that the model captures the weight relation of constraints below, to get successful results. ">" indicates the numerical relation of constraint weights. Other constraints and their weights should be relevant as well, but the inequalities in (152) to (155) must emerge in order to predict the learning trajectory described in (143). Constraints describing the relation between outputs, our main interest, are bold-faced, in order to show their gradual adjustment from the top of the constraint hierarchy along the developmental stages. For the purpose of presentation, the markedness constraint regulating the morphologically conditioned palatalization rule in Korean (*[+anterior, -cont, -strid]#[-cons, +high, -back]) is simplified as *t#i.

(152) The initial stage

OO-IDENT[±Strid] > **t → s /_-Infl**, *t#i, ECONOMY, IO-IDENT[±Strid],
OO-IDENT[±Voi] > *[+son][-voi][+son]

(153) The earlier stages: short but incorrect [d]-final forms from [t]-final base forms

OO-IDENT[±Strid], ECONOMY > **t → s /_-Infl**, IO-IDENT[±Strid], *t#i

[17] This raises a crucial empirical issue: can children in the youngest group understand or produce morphologically complex forms such as nominal compounds? If they do not know complex forms yet (either they cannot produce or they cannot understand complex forms), younger children cannot generate such forms as potential candidates, thus Markedness constraints such as *IO-DEPMORPH do not play any role in determining the outputs at this stage.

*[+son][-voi][+son] > **OO-IDENT[±Voi]**

(154) The intermediate stages: correct but complex [d]-final or [t]-final forms from [t]-final base forms

*t#i > **OO-IDENT[±Strid], t →s /_-Infl** > ECONOMY, IO-IDENT[±Strid]

*[+son][-voi][+son] > **OO-IDENT[±Voi]**

(155) The later stages: short and correct [s]-final forms from [t]-final base forms

*t#i > **t →s /_-Infl** > **OO-IDENT[±Strid]** > ECONOMY , IO-IDENT[±Strid]

*[+son][-voi][+son] > **OO-IDENT[±Voi]**

We also need the constraints to predict the alternation patterns of sonorant-final and noncoronal obstruent-final nouns' alternations. Those alternations are motivated by phonotactic principles in Korean: intervocalic flapping, intersonorant voicing, and coda neutralization of non-coronal obstruents. The relevant markedness constraints were already introduced when the analysis of phonotactic patterns was presented in § 5.2. A suitable weight relation of constraints for analyzing the three alternation patterns is given below. As mentioned earlier, the expected weights presented here are hypothetical values. It would not cause any harm to consider different values, so long as they do not conflict with the constraint weight relation presented here.

Stem-final /l/ alternates with [ɾ] before vowel-initial suffixes, due to the ban against a lateral surrounded by voiced segments. (*[+voi][+lat][+voi]). To predict the alternation, the weight of *[+voi][+lat][+voi] should be higher than the summed weight of *[ɾ], IO-IDENT[±lat], and the output-to-output faithfulness constraint for the feature lateral (OO-IDENT[±lat]).

(156)

/al-a/ base: al	*[+voi][+lat][+voi]	*[ɾ]	OO-IDENT([±lat])	IO-IDENT([±lat])	
weights	20	10	5	1	∑
☞[aɾa]		*	*	*	16
[ala]	*				20

Voiceless obstruents alternate with their voiced counterparts when a sonorant-initial suffix follows. To describe this pattern, the summed weight of faithfulness constraints for voicing (OO-IDENT[±voi], IO-IDENT[±voi]) and *[-son, +voi] should be lower than the weight of *[+son][-voi][+son].

(157)

/ap-a/ base:ap	*[+son][-voi][+son]	*[-son, +voi]	OO- IDENT([±voi])	IO- IDENT([±voi])	
weights	20	10	5	1	∑
☞[aba]		*	*	*	16
[apa]	*				20

/p^h/ and /k^h/ alternate with [p] and [k] in unsuffixed noun forms. Otherwise, the underlying aspiration values are realized faithfully. To describe this alternation, the weight of the input-to-output faithfulness constraint for spread glottis (IO-IDENT[±s.g.]) needs to be lower than the summed weights of the output-to-output faithfulness constraint for the same feature (OO-IDENT[±s.g.]) and *[+s.g.]. Once the weight relation of IO-IDENT[s.g.], OO-IDENT[±s.g.], and *[+s.g.] is determined, the weight of *[+s.g.]# does not matter.

(158)

/ap^h/ base:ap	OO-IDENT([±s.g.])	*[+s.g.]#	*[+s.g.]	IO-IDENT([±s.g.])	
weights	20	10	5	1	∑
☞[ap]				*	1
[ap^h]	*	*	*		35

(159)

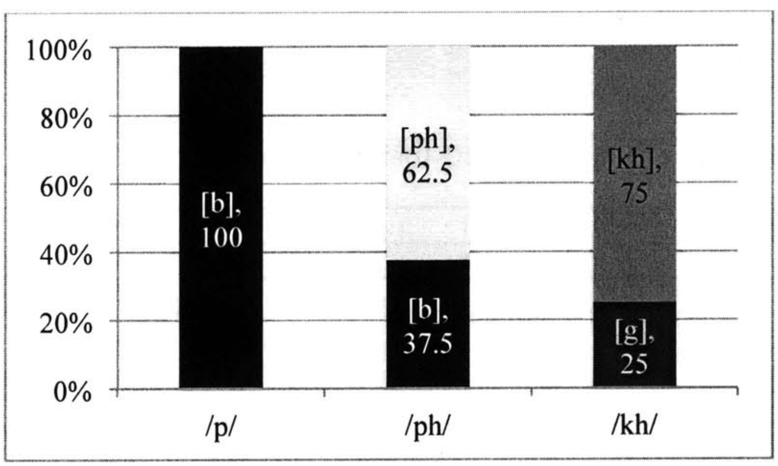
/ap^h-i/ base:ap	OO-IDENT([±s.g.])	*[+s.g.]#	*[+s.g.]	IO-IDENT([±s.g.])	
weights	20	10	5	1	∑
☞[ab-i]				*	1
[ap^h-i]	*		*		25

The same constraint weight relation, the higher weights of an OO-IDENT constraint and the general markedness constraint over the IO-IDENT constraint, holds for analyzing the neutralization of non-coronal tensed (glottalized) obstruents; the sum of the OO-IDENT constraint for constricted glottis and *[+c.g.] should be weighted over the IO-IDENT constraint for the same feature.

5.3.3 Learning simulation

Winners were specified with their type frequencies based on the database (Albright 2008) encoding the entire list of noun stems complied by the National Institute of the Korean Language augmented with token frequency information from Sejong Corpus (Kang and Kim 2004). For sonorant-final nouns, a unique winner was specified in each tableau: non-alternating nouns for vowel-initial suffixed forms of nasal-final nouns and [ɾ]-final forms for lateral-final nouns followed by vowel-initial suffixes. For noncoronal obstruent-final nouns, the attested variants were specified as multiple winners and their frequencies were provided based on the current experimental results. 1,360 for /p/, 64 for /p^h/, 5,994 for /k/, and 18 for /k^h/ from the entire lexicon of Korean noun were distributed into the attested variants in accordance with their proportion observed from the adult participants in the single-picture-description experiment. The observed proportion of each noncoronal obstruent-final variant in the experiment is shown in the graph in (160).

(160) Stem-final noncoronal obstruents from adults' production



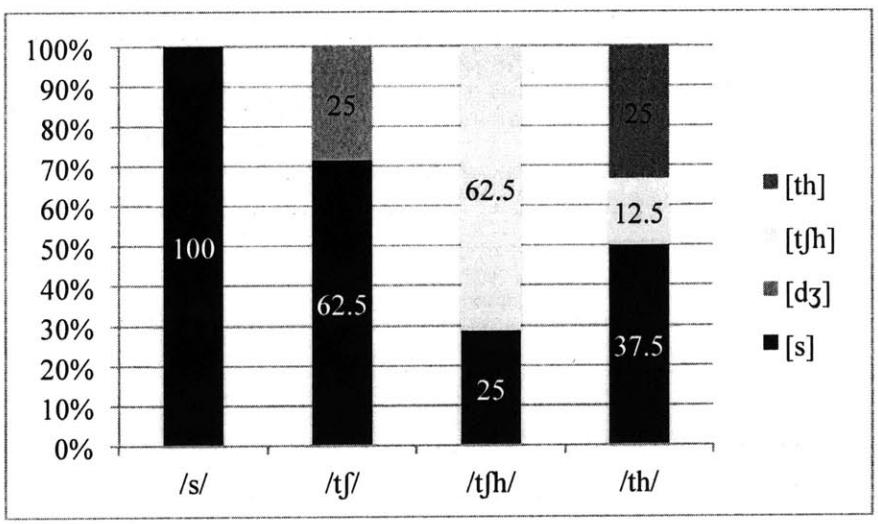
For instance, 18 of /k^h/ in the lexicon were distributed to 5 of [g] and 13 of [k^h], given that in the experiment, 25% of stem-final /k^h/ surfaced as [g], and 75% as [k^h]. As shown in (160), /k/ was not elicited from the experiment. I assumed that /k/ would always surface as [g], given that all /k/s in the paired-picture-description experiment alternated with [g] but never with [k^h]. The frequency of stem-final noncoronal obstruents fed to the model is presented below.

(161) The frequency of stem-final noncoronal obstruents in suffixed forms assumed in input

UR	Base	Suffixed forms	Frequency
/p/	[p]	[b]	1360
		[p^h]	0
/p^h/	[p]	[b]	24
		[p^h]	40
/k/	[k]	[g]	5994
		[k^h]	0
/k^h/	[k]	[g]	5
		[k^h]	13

Along the same lines, the frequency of stem-final coronal obstruent variants was distributed according to the adult production patterns observed in the experiment, repeated in (162) from section 2.1.3.

(162) Stem-final coronal obstruents from adult production



To include morphologically longer forms attested in the intermediate stage, I added the candidate [t#S] (#: a word boundary) for each tableau: stem-final [t] followed by another stem-initial segment. This candidate was always assigned zero frequency, given no such instance from adults.

Assuming the initial bias that OO-IDENT constraints are weighted over markedness constraints, OO-IDENT constraints were assigned a higher weight, 50, than the highest trained weight of a Markedness constraint 38.56, which was generated from the phonotactic learning stage. Within the set of OO-Ident constraints, all constraints were equally weighted. The trained weights of the markedness constraints and the input-to-output faithfulness constraints from the previous phonotactic learning served as the initial weights of two sets of constraints. The σ^2 value was assumed to be equal for all of the constraints employed in learning alternations. To model the learning stages, I modified the adult corpus in such a way that it can represent a child corpus to a reasonable degree. Given that children have a smaller amount of input data than adults, evidence available to adjust constraint weights will be smaller for children than for adults. Based on this assumption, I modeled intermediate learning stages by gradually increasing the values of σ^2. That is, the model was more biased to leave the weights closer to their target weights in earlier learning stages. The same strategy was used to simulate the learning of Korean verb paradigms as well.

5.3.3.1 Final-stage grammar

I first ran the model with a very large sigma value, $\sigma^2 = 10{,}000$, in order to get the predictions when the model is allowed to reweight the constraints to fit the data as closely as possible; this is assumed to correspond to the adult grammar.

The results of the learning are as follows. The model was able to predict the alternation of sonorant-final nouns. Faithful realization of nasal-final nouns was predicted, as was the [l] to [ɾ] alternations. For noncoronal obstruent-final nouns, the model learned variation between a lenis stop and its aspirated counterpart. As shown in (163), no aspirated stops were predicted to surface from underlyingly unaspirated stops. This pattern is identical with the experimental results of adults. The model predicted noncoronal aspirated stops over voiced lenis ones as the most probable surface form of aspirated noncoronal stops. While the probabilities of such surface forms were higher than the experimental results, especially for /kʰ/ to [g], the predicted winners were the same as the most frequent surface forms observed from adults in the experiment.

(163) The prediction of the adult grammar for stem-final noncoronal obstruents

UR	Base	Suffixed forms	Predicted probabilities
/p/	[p]	[b]	100%
		[pʰ]	0%
/pʰ/	[p]	[b]	42%
		[pʰ]	58%
/k/	[k]	[g]	100%
		[kʰ]	0%
/kʰ/	[k]	[g]	39%
		[kʰ]	61%

Variation among coronal obstruent-final nouns was learned. Five variants [s, tʃʰ, tʰ, dʒ, t] were allowed to surface. Neither [d] nor [t#C] was predicted, the same tendency observed from adult speakers. [s] was the most probable winner overall across the five underlying forms. These patterns are the same as the experimental results as well. The predicted probabilities for each variant are given below.

(164) The prediction of the adult grammar for stem-final coronal obstruents

	UR	%	UR	%	UR	%	UR	%	UR	%
[s]	/s/	83	/tʰ/	32	/tʃ/	79	/tʃʰ/	71	/t/	92
[tʰ]		3		51		0		3		1
[dʒ]		2		6		15		10		0
[tʃʰ]		12		11		9		13		0
[d]		0		0		0		0		7
[t#S]		0		0		0		0		0

The model's success in preferring the [s] variant was mainly due to the high trained weight of the anticorrespondence constraint t → s/ _-INF and IO-DEPMORPH, and the large degree of demotion of all OO-IDENT constraints. As shown in (164), [s] was the most frequent among the five coronal obstruent variants, which had an effect on the highest probability of [s]. Other anticorrespondence constraints, such as the t → tʃ/ _-INF constraint or the t → tʃʰ/ _-INF constraint, were in much lower positions than the t → s/ _-INF constraint in the trained grammar. Therefore, the grammar were better able to predict [s] over the other variants. Morphologically longer forms are not predicted, since the primary data sufficiently supported IO-DEPMORPH, both at phonotactic learning stage and at alternation learning stage.

Some discrepancies were found between the model's predictions and the experimental results. First, when we compare the probabilities of [s] from each underlying form, the predicted probability of [s] from /tʰ/ is lowest: in the experiment, however, the probability of [s] from /tʃʰ/ was the lowest. Second, the model occasionally predicted /s/ to surface as [tʃʰ], while in the experiment adults always favored faithful realization [s]. Third, [dʒ] was predicted from /tʃʰ/ as well as from /tʃ/, unlike the experimental results in which only /tʃ/ surfaced as [dʒ].

The observed discrepancies are not hard to understand. Due to the large amount of [s] from /s/, the IO-IDENT([±Strid]) constraint was promoted highly during the learning. As a result, the predicted probability of [s] from /tʰ/ was lower than from /tʃʰ/, which is the opposite of the experimental results. The model's prediction of the /s/ to [tʃʰ] alternation is also mainly due to the high weight of the IO-IDENT([±Strid]), which was supported by the /s/, /tʃ/, and /tʃʰ/ to [s] alternations. The prediction of [dʒ] from /tʃʰ/ was due to the low weights of IO-IDENT constraints for voicing and spread glottis, which were frequently violated from the alternations of stem-final noncoronal lenis stops to voiced stops (i.e., /p/ to

[b], /k/ to [g]) and the alternation of stem-final coronal aspirated stops to [s] (i.e., /tʰ/ to [s], /tʃʰ/ to [s]).

Despite some discrepancies, the model described the patterns of alternations fairly accurately. Most importantly, it predicted [s] as the most probable variant, due to the high weight of the t → s/ _-INF constraint, and the low weight of OO-IDENT[±strid]. Especially from underlying /s/ and /tʃ/, [s] was frequently predicted, due to the high weight of IO-IDENT[±strid].

5.3.3.2 Early-stage grammar

Now we move on from the adult stage to the set of simulations that model the *learning trajectory*. The σ^2 value which was set at 10,000 at the adult stage was decreased. Recall that a smaller sigma value means a greater bias that the learner wants to stick to the target weights of the constraints. When the σ^2 value was 100, the model predicted child forms attested from the youngest group. At this stage, the learning of sonorant-final nouns' alternation and [l] ~ [ɾ] alternations was completed. Noncoronal obstruents were predominantly predicted to surface as voiced lenis stops. This is the same pattern observed from children in the youngest group in the experiment. The table in (165) shows the model's predictions about stem-final noncoronal obstruents.

(165) The prediction for the early-stage grammar for stem-final noncoronal obstruents

UR	Base	Suffixed forms	Predicted probabilities
/p/	[p]	[b]	99%
		[pʰ]	1%
/pʰ/	[p]	[b]	93%
		[pʰ]	7%
/k/	[k]	[g]	100%
		[kʰ]	0%
/kʰ/	[k]	[g]	91%
		[kʰ]	9%

Crucially, the model predicted [d] most frequently from all of the underlying forms of coronal obstruent-final nouns. Recall that this is the 'incorrect' inflection pattern that youngest children produced in the experiments. The table in (166) shows the predicted probabilities of each stem-final coronal obstruent in this stage.

(166) The predictions for the early-stage grammar for stem-final coronal obstruents

	UR	%	UR	%	UR	%	UR	%	UR	%
[s]	/s/	0	/tʰ/	0	/tʃ/	0	/tʃʰ/	0	/t/	0
[tʰ]		0		0		0		0		1
[dʒ]		0		0		0		0		0
[tʃʰ]		0		0		0		0		0
[d]		82		91		83		82		96
[t#S]		18		9		17		18		4

At this stage, the model demoted the OO-IDENT constraint for voicing below the Markedness constraint banning a voiceless segment surrounded by voiced ones, from which it predicted voicing alternations [t] ~ [d]. The OO-IDENT constraint for voicing was demoted faster than the other OO-Ident constraints, because of frequent voicing alternations observed from noncoronal obstruent-final noun stems: while the total frequency of coronal obstruent-final stems is 666, there are 1,424 labial and 6,018 velar obstruent-final stems in Korean, where /p/ and /k/ frequently alternate with [b] and [g]. Thus, even without much evidence for the voicing alternations observed from coronal-final stems, the model found the evidence to demote the OO-IDENT constraint for voicing from the noncoronal obstruent-final nouns' alternations. Morphologically complex forms involving [t] (e.g., [t#S]) were predicted but their probabilities were lower than simpler forms involving [d], because the weight of IO-DEPMORPH was higher than the weight of OO-Ident[±voi] at this learning stage.

All other OO-Ident constraints relevant to the alternation of obstruent-final nouns, OO-IDENT[±strid], OO-IDENT[±cont], OO-IDENT[±d.r.] and OO-IDENT[±s.g.], retained their given high weights. Thus, no stem-final obstruent's alternation except for the voicing alternation was predicted, which describes the state of children in the youngest group.

5.3.3.3 Intermediate-stage grammar

When the σ^2 value was set to 1,000, training yielded the grammar describing the attested intermediate learning stage. For noncoronal obstruent-final nouns, the model predicted some aspirated labial and velar variants, but the lenis ones were overwhelmingly preferred. This is matched by the observed preference from children in the intermediate and oldest groups.

(167) The predictions of the intermediate-stage for stem-final noncoronal obstruents

UR	Base	Suffixed forms	Predicted probabilities
/p/	[p]	[b]	93%
		[p^h]	7%
/p^h/	[p]	[b]	70%
		[p^h]	30%
/k/	[k]	[g]	90%
		[k^h]	10%
/k^h/	[k]	[g]	82%
		[k^h]	18%

For the inflection of coronal obstruent-final nouns, the deviant form [t#S] was more frequently predicted than in the earlier stage. [d] was still the most probable winner from all underlying forms, but compared to the previous stage, the probabilities assigned to [t#S] were higher. [s] was predicted as a variant at this stage, but the other attested variants [tʃ], [tʃ^h] and [t^h] were not predicted yet. The table below shows the prediction of the grammar in this learning stage.

(168) The predictions for the intermediate-stage for stem-final coronal obstruents

	UR	%	UR	%	UR	%	UR	%	UR	%
[s]	/s/	19	/t^h/	4	/tʃ/	11	/tʃ^h/	12	/t/	2
[t^h]		0		0		0		0		1
[dʒ]		0		0		0		0		0
[tʃ^h]		0		0		0		0		0
[d]		52		68		62		59		81
[t#S]		29		28		27		29		17

The predictions above were driven by the adjustment of t → s/ _-INF constraint above IO-DEPMORPH constraint. t → s/ _-INF was promoted from the previous stage due to the high frequency of the [s] found in many suffixed forms of coronal obstruent-final nouns. Under these constraint weights, morphologically complex forms were predicted. The OO-IDENT constraint for stridency still retained its high weight, thus [s], [tʃ] and [tʃ^h] variants were not productively predicted.

5.3.3.4 Later-stage grammar

When the σ^2 value was increased to 3,000, it predicted the state of children in the oldest group. Stem-final noncoronal obstruents most frequently surfaced as voiced lenis stops. Compared to the previous two stages, faithful realizations of aspirated stops were more frequently predicted.

(169) The predictions for the later-stage for stem-final noncoronal obstruents

UR	Base	Suffixed forms	Predicted probabilities
/p/	[p]	[b]	100%
		[pʰ]	0%
/pʰ/	[p]	[b]	87%
		[pʰ]	13%
/k/	[k]	[g]	100%
		[kʰ]	0%
/kʰ/	[k]	[g]	67%
		[kʰ]	33%

For coronal obstruents, the model no longer predicted the [d] variant or [t#S], except from /t/. Instead, [s] was predicted. No other variants were predicted in significant amounts. The patterns are matched by the production patterns we observed from the oldest children in the current experiment.

(170) The predictions of the later-stage for stem-final coronal obstruents

	UR	%	UR	%	UR	%	UR	%	UR	%
[s]	/s/	91	/tʰ/	61	/tʃ/	73	/tʃʰ/	82	/t/	74
[tʰ]		3		15		11		9		6
[dʒ]		2		6		9		2		2
[tʃʰ]		4		18		7		7		3
[d]		0		0		0		0		15
[t#S]		0		0		0		0		0

This prediction was possible due to the high weight of t → s/ _-INF. This constraint was assigned the highest weight among all of the constraints assumed at this stage. The model demoted the OO-IDENT[±STRID] constraint below t → s/ _-INF, thus it predicted the stridency alternation.

IO-IDENT constraints play a crucial role in predicting the current result as well. The frequent surface realization of [s] provides evidence to promote the IO-IDENT[±STRID] constraint, because it is frequently supported by the faithful realization of /s/ to [s]. By contrast, alternations /tʃʰ/ or /tʰ/ to [s] contribute to demote the IO-IDENT[±CONT] and the IO-IDENT[±d.r] constraints. Thus, [s] is predicted as the most probable variant, as a result of promoting the IO-IDENT[±STRID] constraint and demoting OO_IDENT[±STRID].

In sum, the model in which OO-IDENT constraints were given an initial bias correctly predicted the attested learning trajectory. Specifically in this learning model, OO-IDENT constraints were evaluated by comparing the output with its base form of the paradigm. This result indicates that the process of learning alternations can be understood as a biased learning, where learners initially have a strong preference to inflect items faithful to the base form, and gradually allow alternations according to the violation of faithfulness constraints found in the primary data. I support this claim with the additional evidence of learning Korean verb paradigms.

5.4 Learning alternations from Korean verbs

5.4.1 Attested learning trajectory

While the current study did not trace the learning trajectory of each child, the experimental results systematically showed an implicational relation between the alternations that child participants mastered; if a child acquired a particular alternation A, he or she showed the mastery of another alternation B. I assume that a child mastered an alternation if a correct inflected form exhibiting the alternation was systematically observed among the child's productions across the single-picture-description test and the paired-picture-description test. If a child produced at least one instance of an incorrect or a deviant form involving an alternation, he or she is considered to have incomplete knowledge of the alternation. The implicational relation between the alternations is illustrated in (171). The mark "⥣" indicates that the mastery of the alternations following ⥣ implies the mastery of the alternations preceding ⥣.

(171) Implicational relation between the mastery of alternations

Earliest-acquired alternations

Voicing	/ap-a/ → [aba], /at-a/ →[ada], /ak-a/ → [aga]
Nasal	/ap-na/ → [amna], /at-na/ →[anna], /ak-na/ → [aŋna]
Lateral	/ al-a/ → [aɾa]
Coda neutralization	/ as,at^{h}, atʃ, atʃ^{h}-ta / → [att'a], /ap^{h}-ta/→ [apt'a] /ak^{h}-ta/ →[akt'a]

⥣

Later-acquired alternations

w ~ p ~ m	/aw-a/ → [awa], /aw-ta/ → [apt'a], /aw-na/ → [amna]
ɾ ~ t ~ n	/al-a/ → [aɾa], /al-ta/ → [att'a], /al-na/ → [anna]

⥣

Latest-acquired alternations

ll ~ ɾ	/all-a/ → [alla], /all-ta/ →[aɾɨda], /all-na/ →[aɾɨna]
ɾɨɾ ~ ɾɨ	/aɾɨɾɨ-ə/ → [aɾɨɾiə] , /aɾɨɾɨ-ta/ →[aɾɨda], /aɾɨɾɨ-na] →[aɾɨna]
l ~ [ ]	/alna/ →[ana]

Given that many alternations exist to bring the sequences into the conformity with phonotactic principles, learners' phonotactic knowledge must be a powerful tool to understand phonotactically predictable alternations. This indicates that the promotion of Markedness constraints that are supported by phonotactic restrictions (Fikkert 2000) may help learners to acquire phonotactically-motivated alternations earlier; even if OO-CORR constraints are not demoted enough, the promotion of the Markedness constraints above the relevant OO-CORR constraints can predict the alternations.

The implicational relation also indicates that the frequency of overlapping features, not the frequency of segmental alternations, constitutes the evidence to learn patterns of alternation. For instance, stem-final coronal obstruents are relatively rare in Korean verb paradigms, thus alternations such as [d] ~ [t] are underrepresented. The frequency of early-acquired [d] ~ [t] alternations is even lower than the frequency of [ll] ~ [ɾɨ] alternations which are acquired last in (171) – the type frequency of segmental alternations in the database of 952 inflected verbs compiled by Albright and Kang (2008) which bases the type frequency information on the Sejong corpus (Kang and Kim 2002), shows 13 [d]~ [t] alternations but 59 [ll] ~ [ɾɨ] alternations. However, due to the large number of sources showing the voicing alternation (50 of [b] ~ [p] and 22 of [g] ~ [k]), the segmentally underrepresented [d] ~ [t] alternation seemed to be acquired earlier than segmentally more frequent [ll] ~ [ɾɨ] alternation. Another such example is [$tʃ^h$]~ [t]. In the database, only one [$tʃ^h$]~ [t] alternation is attested. However, the coda neutralization process found in this alternation is supported by other segmental alternations such as 13 [t^h]~ [t] and 7 [p^h]~ [p].

Also, the acquisition of a segmental alternations is delayed if the alternation involves at least one feature modification whose acquisition is late. For instance, the patterns involving nasal as well as continuancy alternations [w]~[m] and [ɾ]~[n] are not produced by a learner who has not figured out [w]~[p] and [ɾ]~[t] alternations. While the nasal alternation is already acquired, as the early acquisition of [d]~[n], [g]~[k], [g]~[ŋ] alternations shows, [w] ~ [p] and [ɾ] ~ [t] alternations are not yet acquired in the attested intermediate stages. The results show that the acquisition of the alternation patterns is delayed if a late-acquired featural change is involved in the alternation where multiple features change (e.g., [w]~[n], [ɾ]~[n], and [s]~[n]).

What predicts the implicational relation between the later-acquired and latest-acquired alternations? As mentioned, neither of the alternations are phonotactically perfectly predictable. The frequency of the segmental features does not help, since [ll] ~ [ɾ], [ɾɨɾ] ~ [ɾɨ], and [l] ~ [] alternations are more frequent than [w] ~ [p] and [ɾ] ~ [t] alternations. Crucially, there are shared structural changes that can be observed among the patterns that are acquired in the similar stages: both of later-acquired alternations in (171) involve change of the features continuant, sonorant and nasal, and three of latest-acquired alternations in (171) exhibit deletion of lateral.

Do young learners tend to generalize the shared structures across different segmental alternations when they learn patterns of alternations? With initially undominated OO-CORR constraints, can the demotion of the constraints described based on shared structural changes predict the attested order of acquisition? If not, does it suggest critical learning biases that need to be incorporated into the grammar?

5.4.2 The target grammar

I present the grammar of the final adult stage, which learners acquiring the patterns of alternation are expected to reach. The set of alternations is summarized in table (172). I assume that underlyingly there are three types of suffixes, -a/-ə, obstruent-initial, and sonorant-initial ones, and that the vowel -ɨ before some sonorant-initial suffixes is epenthesized. If [-ɨ] had been an underlying vowel, there is no reason to delete the lateral in /al-ɨni/ as [ani] shown in (d); [aɾɨni] is a phonotactically legal sequence in Korean, thus there is no need to repair the sequence. All of the sonorant-initial suffixes that do not allow -ɨ epenthesis are /n/-initial; I call those suffixes–N suffixes. Sonorant-initial suffixes that allow -ɨ epenthesis are /n/-, /m/-, and /l/-initial ones: -ɨSon suffixes. Stem-final laterals in the paradigm (d) behave differently depending on the initial segment of -ɨSon suffixes. /l/ is deleted before /-n/, while it is preserved before /-m/ and /-l/, as shown in the cell of -ɨSon suffixed forms in (d).

(172) Types of alternations in Korean verb paradigms

Stems in UR	-a/-ə	-ta (-Obs)	-ɨ-ni (-ɨ-Son)	-ni (-N)
a. /ap/	ab-a	ap-ta	ab-ɨ-ni	am-ni
b. /am/	am-a	am-t'a	am-ɨ-ni	am-ni
c. /ap^h,ap'/, / ak^h,ak'/ / as,at^h,adʒ,a$tʃ^h$/	a[p^h,p']-a, a[k^h,k']-a a[s,t^h,dʒ, $tʃ^h$]-a	a[p]-t'a, a[k]-t'a a[t]-t'a	a[b]-ɨ-ni, a[g]-ɨ-ni a[s,t^h,dʒ, $tʃ^h$]-ɨ-ni	a[m]-ni, a[ŋ]-ni a[n]-ni
d. /al/	aɾ-a	al-da	a-ni (cf. al-myən, al-liɾa)	a-ni
e. /alɨ/	aɾ-a	aɾɨ-da	aɾɨ-ni	aɾɨ-ni
f. /al/	aɾ-a	at-t'a	aɾ-ɨ-ni	an-ni
g. /aw/	aw-a	ap-t'a	au-ni	am-ni
h. /au/	aw-a	au-da	au-myən	au-ni
i. /aɾɨl/	aɾɨɾ-ə	aɾɨ-da	aɾɨ-myən	aɾɨ-ni
j. /all/	all-a	aɾɨ-da	aɾɨ-myən	aɾɨ-ni

I first provide additional evidence in support of treating -ɨ in -ɨ-Son suffixes as an epenthetic vowel, before analyzing the patterns of the stem-final segments' alternations. A non-lateral non-nasal consonant followed by a nasal consonant is illegal in Korean (*[-lat, -nas][+nas]). The illegal sequences are repaired either by vowel insertion or by nasal assimilation –i.e., -ɨ-Son suffixes and –N suffixes. Together with the difference in the distribution of initial segments within -ɨ-Son suffixes (/n/, /m/, and /l/) and –N suffixes (only /n/), the two types of suffixes are distinctive in their syntactic structure: the latter suffixes (-N suffixes) are found in matrix clauses (e.g., *-ni* 'interrogative', -ne 'indicative'), the former ones (-ɨ-Son suffixes) are used in subordinate clauses[18] (e.g., *-ɨmyən* 'if', *-ɨni* 'since', *-ɨrə* 'in order to', *ɨnik'a* 'because', *ɨna* 'although' etc.). As a result of epenthesis, the underlying values of a proceeding segment before -ɨSon suffixes are preserved except for the voicing of obstruent (e.g., /cap-ni/ 'catch-since'→ [cabɨni]), while the segments alternate to their nasal counterparts before -N suffixes (e.g., /capni/ 'catch-interrogative'→ [camni]). In the current study, I do not attempt to explain why suffixes found in subordinate clauses show a stronger tendency to preserve underlying values of the stems, compared to those found in matrix clauses. What is crucial to the current consideration is that -ɨSon suffixes and -N suffixes do behave differently; thus it is reasonable to assume distinctive constraints relevant to vowel epenthesis for each class of suffix. I assume a general faithfulness constraint barring ɨ insertion (IO-Dep ɨ) as well as a lexically specific faithfulness constraint which disallows ɨ insertion specifically in matrix clauses as (173).

(173) IO-Dep $ɨ_{MatrixSon}$: Do not insert ɨ before sonorant-initial suffixes that are located in matrix clauses

*[-lat,-nas][+nas] is an undominated markedness constraint in the language. To predict nasal assimilation before -N suffixes, IO-Dep $ɨ_{MatrixSon}$ should be weighted higher than the summed weights of the OO-Ident constraint for nasality (OO-Ident[±nas]) and the IO-Ident constraint for nasality (IO-Ident[±nas]). Recall that OO-Ident constraints compare the base form and the output of a paradigm. Throughout this section, I give the stem found in the base form for each tableau, which is compared with the stem of the output.

(174) Nasal altenation

/cap-ni/ 'catch-interogative' base: cab-	*[-lat,-nas][+nas]	IO-Dep $ɨ_{MatrixSon}$	OO-Ident [±nas]	IO-Ident [±nas]	IO-DEP ɨ	
weights	30	20	10	3	2	Σ
☞cam-ni			*	*		13
cap-ni	*					30
cab-ɨ-ni		*			*	22

Sequences having -ɨSon suffixes vacuously satisfy the Dep $ɨ_{MatrixSon}$ constraint, because these suffixes are not the ones found in matrix clauses. To predict ɨ insertion in subordinate clauses, the general IO-Dep

[18] Some of the ɨ-initial suffixes are found in matrix clauses, such as -ɨso 'propositive', ɨsige, -ɨsosə 'honorific propositive', but they are rarely used in spoken Korean, and productive in written Korean especially in old texts.

ɨ constraint should be weighted lower than the sum of the OO-Ident [±nas] constraint and the IO-Ident [±nas] constraints.

(175) -ɨ insertion

/cap-ni/ 'catch-since' base: cab-	*[-lat,-nas][+nas]	OO-Ident[±nas]	IO-Dep ɨ	IO-Ident[±nas]	
weights	30	10	8	5	Σ
cam-ni		*		*	15
cap-ni	*				30
☞ cab-ɨ-ni			*		8

Lateral-final verb stems neither undergo nasal assimilation nor allow ɨ insertion when sonorant-initial suffixes follow. As (d) in the table (172), /l/ is faithfully realized before other suffixes in subordinate clauses (i.e., /m/ and /l/ initial suffixes), but /l/ is deleted before suffixes starting with /n/. –N suffixes trigger /l/ deletion as well. In monomorphemic words, a lateral triggers lateralization of the following nasal (i.e., /ln/ → [ll]), and deletion of /l/ before a nasal is a specific alternation pattern found in the verb paradigms. To describe the pattern, I employ a paradigm-specific markedness constraint banning the [+lat][+nas, +coronal] sequence, or *ln (Kenstowicz and Sohn 2008). This constraint is undominated within verb paradigms. I describe the deletion of the lateral as a violation of the faithfulness constraints for lateral (OO-Max [+lat], IO-Max[+lat]). The sum of OO-Max [+lat] and IO-Max[+lat] constraints must be lower than the weight of the IO-Ident [±nas] constraint in order to block the nasal in the suffix from undergoing lateralization. The summed weight of the OO-Max [±lat] and IO-Max[±lat] constraints must also be lower than the weight of IO- Dep $ɨ_{MatrixSon}$ in order to not predict -ɨ insertion in matrix clauses. The faithfulness constraints describing the identity of lateral are relevant as well (IO-Ident [±lat] and OO-Ident[±lat]), which penalize flapping. The weights of these constraints are not critical, since the candidates which violate those constraints already violate other highly-weighted constraints, as in (176).

(176) /l/ deletion before sonorant-initial suffixes in matrix clauses

/sal-ni/ 'live-interrogative' base: saɾ-	*ln	IO-Dep $ɨ_{MatrixSon}$	IO-Dep ɨ	IO-Ident [±nas]	OO-Max [+lat]	IO-Max [+lat]	IO-Ident [±lat]	OO-Ident [±lat]	
weights	30	20	3	3	1	1	1	1	Σ
☞sa-ni					*	*			2
sal-ni	*							*	31
saɾ-ɨ-ni		*	*				*		24
sal-li				*				*	4

/l/ is deleted before sonorant-suffixes in non-matrix clauses as well. This means that the constraint IO-Dep -ɨ should be weighted higher than the sum of OO-Max [±lat] and IO-Max[±lat].

(177) /l/ deletion before sonorant-initial suffixed in non-matrix clauses

/sal-ni/ 'live-since' base: saɾ-	*ln	IO-Dep ɨ	IO-Ident [±nas]	OO-Max [+lat]	IO-Max [+lat]	IO-Ident [±lat]	OO-Ident [±lat]	
weights	30	10	3	1	1	1	1	Σ
☞sa-ni				*	*			2
sal-ni	*						*	31
saɾ-ɨ-ni		*				*		11
sal-li			*				*	4

The ranking in (177) is consistent with an analysis of /-ɾɨɾ/-final verbs ((i) in (172)) in which the underlying form is /Vɾɨl/ and the latter [l] is lost before the following consonant both in matrix and subordinate clauses.

(178) /ɾɨl/~ [ɾɨ] alternation

/iɾɨl-ni/ 'reach-interrogative' base: iɾɨɾ-	*ln[19]	IO-Dep $ɨ_{MatrixSon}$	OO-Max [+lat]	IO-Max [+lat]	IO-Ident [±lat]	OO-Ident [±lat]	
weights	30	20	1	1	1	1	Σ
☞iɾɨ-ni			*	*			2
iɾɨɾ-ɨ-ni		*			*		22
iɾɨl-ni	*					*	32

(179)

/iɾɨl-ni/ 'reach-since' base: iɾɨɾ-	*ln	IO-Dep ɨ	OO-Max [+lat]	IO-Max [+lat]	IO-Ident [±lat]	OO-Ident [±lat]	
weights	30	10	1	1	1	1	Σ
☞iɾɨ-ni			*	*			2
iɾɨɾ-ɨ-ni		*			*		11
iɾɨl-ni	*					*	31

[19] When an obstruent-initial suffix follow, [l] is deleted as well –e.g., /ilɨl-da/ → [iɾɨ-da]. I stipulate the lexically specific *ld constraint for this class of items as $*ld_{/Vlɨl/}$. This constraint is also undominated in the constraint hierarchy.

The lower weight of the OO-Max[+lat] and IO-Max[+lat] constraints compared to the IO-Dep ɨ and IO-Dep $ɨ_{MatrixSon}$ constraints can also account for the alternation found in /Vll/-final verbs. Stem-final geminate /ll/ is banned before a consonant (*CCC), and -ɨ is epenthesized after the geminate. The epenthesis applies both in matrix and in subordinated clauses. Instead of keeping the geminate after the epenthesis (e.g., /all-ni/ → [all-ɨ-ni]), the second /l/ is deleted; OO-Max[+lat] and IO-Max[+lat] constraints should be weighted more than the IO-Dep ɨ constraint and IO-Dep $ɨ_{MatrixSon}$ constraint. I stipulate a markedness constraint *lɨ, a sequence which is never found within monomorphemic words in the language[20]. To predict the pattern, the weight of the markedness constraint *lɨ should be higher than the summed weights of OO-Max[+lat] and IO-Max[+lat] constraints. The same constraint weight relation holds in matrix clauses as well –i.e., the IO-Dep $ɨ_{MatrixSon}$ constraint in the position of the IO-Dep -ɨ constraint.

(180)/Vll-C/ ~ [Vɾ-ɨ-C] alternations

/koll-ni/ 'choose-since' base:kall-	*CCC	*ln[21]	*lɨ	IO-Dep ɨ	OO-Max [+lat]	IO-Max [+lat]	IO-Ident [±lat]	OO-Ident [±lat]	
weights	30	30	30	10	1	1	1	1	Σ
☞aɾ-ɨ-ni				*	*	*	*	*	14
all-ni	*								30
all-ɨ-ni			*	*					40
al-ni		*			*	*			32

Consider now the behavior of vowel-final stems. Due to a constraint barring vowel hiatus (*VV), underlying stem-final vowels are deleted before suffix-initial vowels. One such case is shown in (172) before, which is repeated in (181). This indicates that the weight of the faithfulness constraint for preserving a vowel (IO-Max [-cons]) should be less than the weight of *VV.

(181)

Stems in UR	-a/-ə	-ta (-Obs)	-ɨ-ni (-ɨ-Son)	-ni (-N)
/alɨ/	aɾ-a	aɾɨ-da	aɾɨ-ni	aɾɨ-ni

[20] Inspection of the lexicon shows that all of the singleton vowels in Korean are found after the lateral. I do not have any intuition at the moment why specifically -ɨ is banned after the lateral. The /lɨ/ sequence is frequent after a vowel, thus the surface forms which underwent intervocalic flapping [ɾɨ] are widely attested in Korean lexicon.

[21] This class belongs to the lexical items assumed in $*ld_{/Vlɨl/}$.

(182) /alɨ-a/ ~ [aɾ-a] alternations

/t'alɨ-a/ 'follow-imperative' base: 't'aɾ-'	*VV	IO-Max [-cons]	
weights	20	5	∑
☞aɾ-a		*	5
aɾɨ-a	*		20

Until now we have analyzed the alternation patterns of obstruent-final verbs in (a) and (c) in the table (172), lateral-final verbs in (d), (i), and (j), and vowel-final verbs in (e). The voicing alternation in (a) and (c), coda neutralization in (c), and intervocalic flapping in (d) are patterns of alternation found in the noun paradigms as well, the analyses of which were already provided in section 5.2.2. Nasal-final stems' paradigms as in (b) are uniform. So, the patterns that are left for analysis are (f), (g), and (h) in the table (172), summarized in (183). I start the remaining analyses beginning with the pattern (h).

(183)

Stems in UR	-a/-ə	-ta (-Obs)	-ɨ-ni (-ɨ-Son)	-ni (-N)
f. /al/	aɾ-a	at-t'a	aɾ-ɨ-ni	an-ni
g. /aw/	aw-a	ap-t'a	au-ni	am-ni
h. /au/	aw-a	au-da	au-myən	au-ni

Stem-final /u/ alternates with [w] before –a/-ə initial suffixes. The pattern is in (h) in (172). The lower weight of the faithfulness constraint preserving a mora from the input to output mapping (IO-Max(μ)) compared to the summed weight of *VV and the faithfulness constraint realizing the mora in the input to the output (OO-Max(μ)) can describe this alternation pattern.

(184)

/s'au-ə/ 'fight-imperative' base:'s'aw-	*VV	IO- Max(μ)	OO-Dep(μ)	
weights	15	23	10	∑
☞s'aw-ə		*		23
s'au-ə	*		*	25

Before consonant-initial suffixes, stem-final /u/ is realized faithfully; different from the case in (184), /u/ does not alternate to [w], and different from the following case in (186), /u/ is not realized as [p]. To predict the candidate exhibiting vowel hiatus as the winner (i.e., /auC/ → [auC]), *VV should be weighted less than the constraint barring a sequence involving a glide followed by a consonant *wC, which is undominated in the language. To avoid the /u/ to [p] alternation, the summed weights of the faithfulness constraints for the feature sonorous (IO- Ident[±son] and OO- Ident[±son]) and for the feature consonantal (IO- Ident[±cons] and OO- Ident[±cons]) should be higher than *VV.

(185)

/s'au-ta/ 'fight-decl'	*wC	IO-Ident[±cons]	OO-Ident[±cons]	IO-Ident[±son]	OO-Ident[±son]	*VV	
weights	30	10	10	5	5	10	Σ
☞s'au-da						*	10
s'aw-da	*						30
s'ap-t'a		*	*	*	*		30

Stem-final /w/ is faithfully realized before –a/-ə suffixes, as shown in (i) in (172). [w] followed by a vowel does not involve hiatus, thus the sequence is not subject to any repair. Stem-final /w/ becomes [p] before obstruent-initial suffixes, and [n] before sonorant-initial suffixes. I formulate the alternation of /w/ with a markedness constraint barring a glide followed by a consonant (*wC), which is undominated in the language. A potential candidate exhibiting the alternation /wC/ → [uC] (e.g., [tou-da] in (186)) is disfavored by a highly-weighted faithfulness constraint barring the insertion of a mora (IO-Dep (μ)). The relation between *wC and IO-Dep(μ) is not determined yet (see the tableau (188)). The winning candidate involving the alternation /wC/ → [pC] shows a change of the feature sonorant and continuant between the input and output as well as between the base and the output. Thus, the summed weights of faithfulness constraints for the feature sonorous (IO-Ident[±son] and OO- Ident[±son]) and those for the feature continuant (IO-Ident[±cont] and OO- Ident[±cont]) should be lower than the weights of *wC and the weight of IO-Dep(μ).

(186)

/tow-ta/ 'help-decl' base:tow-	*wC	IO- Dep(μ)	IO-Ident [±son]	OO- dent [±son]	IO-Ident [±cont]	OO- Ident [±cont]	
weights	30	30	5	5	5	5	Σ
☞top-t'a			*	*	*	*	20
tow-da	*						30
tou-da		*					30

Before –N-initial suffixes, the pattern /tow-ni/ is realized as [tom-ni]; the feature nasal and continuant alternate. To disallow [tou-ni], which has an extra mora compared to the input, the weight of IO-Dep(μ)$_{MatrixSon}$ should be higher than the summed weights of all faithfulness constraints the winner violates: IO- Ident[±nas], OO- Ident[±nas], IO- Ident[±cont], and OO- Ident[±cont].

(187)

/tow-ni/ 'help-interrog' base:tow-	*wC	*[-lat,-nas] [+nas]	IO-Dep(μ) MatrixSon	IO-Ident [±nas]	OO-Ident [±nas]	IO-Ident [±son]	OO-Ident [±son]	IO-Ident [±cont]	OO-Ident [±cont]	
Weights	30	30	30	5	5	5	5	5	5	∑
☞tom-ni				*	*			*	*	20
tow-ni	*									30
tou-ni			*							30
top-ni		*				*	*	*	*	50

Before -ɨSon suffixes, however, /tow-ni/ → [touni] pattern is observed. In other words, -ɨ is inserted to protect the stem-final segment from undergoing the nasal alternation, and the /w-ɨ/ sequence is realized as [u]. Thus I consider that the first candidate in (188) violates the IO-Dep(μ) constraint. To predict /wn/ → [un] instead of /wn/ → [mn], IO-Dep(μ) should be weighted less than the summed weights of IO-Ident[±nas] and OO- Ident[±nas].

(188)

/tow-ni/ 'help-since' base:tow-	*wC	IO-Ident [±nas]	OO-Ident [±nas]	IO-Dep (μ)	IO-Ident [±son]	OO-Ident [±son]	IO-Ident [±cont]	OO-Ident [±cont]	
Weights	30	5	5	8	5	5	5	5	∑
☞tou-ni				*					8
tow-ni	*								30
tom-ni		*	*						10
tob-ɨ-ni				*	*	*	*	*	28

The low weight of IO- Ident[±son] and OO- Ident[±son] and IO- Ident[±cont] and OO- Ident[±cont] constraints is relevant to the /lC/ → [tC] alternation in some specific lexical items. The pattern is in (f) in (172). As with the verbs in the /Vlɨl/ class, this group of verbs is assumed not to tolerate [ld] or [ln] sequences. The lower summed weights of IO- Ident[±son], OO- Ident[±son], IO- Ident[±cont], and OO-Ident[±cont] constraints compared to the weight of $*ld_{/Vl\text{ɨ}l/}$ and the weight of IO-Dep ɨ predict the correct alternation, rather than the candidate with unwanted consonant sequence [ld] or vowel insertion. The same is true in matrix clause as well (IO Dep-$ɨ_{MatrixSon}$ in place of IO Dep-ɨ constraint).

(189)

/tɨl-ta/ 'listen-decl' base:tiɾ-	*ld$_{/Vlɨl/}$	IO- Dep ɨ	IO-Ident [±son]	OO-Ident [±son]	IO-Ident [±cont]	OO-Ident [±cont]	IO-Ident [±lat]	OO-Ident [±lat]	
weights	30	30	5	5	5	5	5	5	Σ
☞tɨt-da			*	*	*	*	*		25
tɨl-da	*							*	35
tiɾ-ɨ-ta		*					*		35

5.4.3 Learning simulation

Recall our expectations. If the model correctly predicts the attested learning trajectory, it is supposed to learn the paradigms involving alternation patterns also found in monomorphemic words first, followed by w ~ p, and ɾ ~ t, which are found only in verb paradigms, and lastly it will learn the alternations involving the deletion of the lateral such as lɨl ~ lɨ, ll ~ lɨ, and l ~ [ ], again restricted only within verb paradigms. The types of alternations and their order of acquisition were given in (172).

The method for modeling the learning trajectory was the same as the simulation of the noun alternations in the previous section: assuming the initial bias on OO-IDENT constraints, OO-IDENT constraints were initially weighted above the highest trained weight of the markedness constraints—i.e., target weights of OO-IDENT constraints = 30, which is higher than the highest trained weight of markedness constraints = 15.56. Within the set of OO-IDENT constraints, all of the constraints were equally weighted. The initial weights of markedness constraints and the input-to-output faithfulness constraints were assumed to be their trained weights from phonotactic learning.

5.4.3.1 Final-stage grammar

To check whether this model has an ability to predict the correct adult grammar, I first simulated the final learning stage by assuming a relatively large σ^2 value: constraints were given much freedom to adjust the target weights when the MaxEnt model was faced with constraint violations. When the σ^2 value was 1,000, the model predicted all alternation patterns found in the Korean verb paradigms correctly, as in (172). In other words, alternation data in the primary data triggered the adjustment of the weights of OO-CORR constraints to a proper degree, so that they are weighted lower than the relevant Markedness constraints.

It has been reported in the literature, though, that Korean adult speakers do not always produce the correct forms of alternating verbs, as observed from diachronic variations and production errors (Kang 2006). When the σ^2 value decreases, does this model predict some erroneous alternating forms? If so, will the shape of errors that the model produce close to the final adult-stage be similar to the attested errors from adults? I report the model's prediction when the σ^2 value was 8,00, at which point the predicted outputs matched well with the attested adult production patterns. In the following tables from (190) to (192), the expected winners are given for each paradigm cell, and wrongly predicted outputs by the model are shown in parenthesis with an asterisk marker (e.g., (*ar-ini) in (d)).

(190)

Stems in UR	-a/-ə	-ta (-Obs)	-ɨni (-ɨSon)	-ni (-N)
a. /ap/	ab-a	ap-ta	ab-ɨ-ni	am-ni
b. /am/	am-a	am-t'a	am-ɨ-ni	am-ni
c. /apʰ,ap'/, / akʰ,ak'/ / as,atʰ,adʒ,atʃʰ/	a[pʰ,p']-a, a[kʰ,k']-a a[s,tʰ,dʒ, tʃʰ]-a	a[p]-t'a, a[k]-t'a a[t]-t'a	a[b]-ɨ-ni, a[g]-ɨ-ni a[s,tʰ,dʒ, tʃʰ]-ɨ-ni	a[m]-ni, a[ŋ]-ni a[n]-ni
d. /al/	aɾ-a	al-da	a-ni (*aɾ-ɨ-ni)	a-ni (*aɾ-ɨ-ni, *al-li)
e. /alɨ/	aɾ-a	aɾɨ-da	aɾɨ-ni	aɾɨ-ni
f. /al/	aɾ-a	at-t'a	aɾ-ɨ-ni	an-ni
g. /aw/	aw-a	ap-t'a	au-ni	am-ni
h. /au/	aw-a	au-da	au-ni	au-ni
i. /aɾɨɾ/	aɾɨɾ-ə	aɾɨ-da (*aɾɨɾ-ɨ-da)	aɾɨ-ni (*aɾɨɾ-ɨ-ni)	aɾɨ-ni (*aɾɨɾ-ɨ-ni)
j. /all/	all-a	aɾɨ-da (*all-ɨ-da)	aɾɨ-ni (*all-ɨ-ni)	aɾɨ-ni (*all-ɨ-ni)

As shown, the model preferred to alternate stem-final /l/ with [ɾ], where the deletion of /l/ is expected. Such errors are shown in (d), (i), and (j) in the table above.

Due to the fact that the markedness constraint *ld was indexed to the paradigms (f), (i), and (j), but not (d), the model correctly predicted surface realization of the [ld] sequence in paradigms like (d), and it disfavored the [ld] sequence only in the paradigms which were indexed for the *ld constraint. However, the way that the model repairs the *ld sequence in the (i) and (j) paradigms was incorrect at this stage; instead of deleting /l/ before obstruent-initial suffixes, it preferred to insert the vowel -ɨ.

Recall that the markedness constraint *ln was not indexed, since the [ln] sequence is not allowed across all verb paradigms. In this stage of learning, *ln was assigned a very high weight. The sequence is supposed to be repaired by -ɨ epenthesis in paradigms like (f), but the result showed that the lateral is deleted before /n/ in the paradigms (d), (i), and (j). As the incorrect predictions indicate, the current learning model normally preferred to epenthesize ɨ between the [ln] cluster and then apply intervocalic flapping of /l/ to [ɾ].

Before –N suffixes, /l/ is occasionally preserved and triggers lateralization of the following suffix-initial /n/. The error is *al-li in (d) in the table above. The expected outcomes, /l/ deletion before /n/, were not predicted here. This incorrect outcome of lateral final stems also suggests that the model predicted vowel epenthesis more broadly than it was expected to do.

However, this does not mean that the model generally failed to demote all DEP -ɨ constraints at this learning stage. The model did distinguish the contexts to which it applies vowel epenthesis from the contexts where the nasal alternation is applicable, as the different alternations of stems before *-ini* (-iSon) and *–ni* (-N) suffixes indicate: it normally does not insert vowels before –N suffixes. This part of the success was achieved by the lower trained weight of the IO-DEP $ɨ_{MatrixSon}$ compared to the faithfulness constraints for nasality and the higher trained weight of IO-DEP ɨ compared to those constraints.

The model incorrectly epenthesized a vowel specifically for lateral-final stems, where the deletion of the lateral was expected. This is attributed to the relatively high trained weights of IO-MAX [+lat] and OO-MAX [+lat] and the low trained weights of IO-IDENT[±lat] and OO-IDENT[±lat]. Mainly from the large amount of evidence that /l/ before –a/-ə suffixes undergoes flapping as in the paradigms (d) (as well as from the flapping found in the stem-medial position), the model demoted IO-IDENT[±lat] and OO-IDENT[±lat] constraints to very low rankings, and thus easily learned /l/ ~ [ɾ] alternations. Compared to the flapping, the instances showing the deletion of lateral are less frequent. As a consequence, IO-MAX [+lat] and OO-MAX [+lat] constraints were assigned higher weights than IO-DEP -ɨ and IO-DEP $ɨ_{MatrixSon}$ constraints; thus vowel epenthesis is predicted.

In fact, vowel epenthesis is indeed a widely observed reanalysis pattern from adult Korean speakers in the context where the deletion of a lateral is expected (Kenstowicz and Sohn 2008). What makes speakers consider that vowel epenthesis is a better repair than the deletion of the lateral? Examination of the table (190) suggests that there is a unified pattern among the errors: errors involve the stem form that is faithful to the stem of the base form. So my guess, along the same logic with Kenstowicz and Sohn (2008), is that the reanalysis that the adult speakers make can be understood as a tendency to preserve paradigm uniformity. The current learning simulation result actually matches well with such speakers' error patterns, which may show remnants of the initial learning bias.

5.4.3.2 Early-stage grammar

Assuming that the trained grammar reached the adult-like stage, I started to simulate childhood stages. Employing the same method applied in learning noun paradigms, the σ^2 value decreased gradually. I now report the training results from the earliest learning stage representing the younger children's grammar to the later stages.

When the σ^2 value was set to 10, the model's predictions matched the attested production patterns found from younger children in the experiment. At this very early stage, the model mastered the learning of vowel ɨ elision, the l ~ ɾ alternation, the voicing alternation, and coda neutralization, as shown in (191). As before, the incorrect surface forms that the current model prefers most among the candidates are given in parenthesis.

(191)

Stems in UR	-a/-ə	-ta (-Obs)	-ɨni (-ɨSon)	-ni (-N)
a. /ap/	ab-a	ap-ta	ab-ɨni	am-ni (*ab-ɨ-ni)
b. /am/	am-a	am-t'a	am-ɨni	am-ni
c. /ap^h,ap'/, / ak^h,ak'/ / as,at^h,adʒ,atʃ^h/	a[p^h,p']-a, a[k^h,k']-a a[s,t^h,dʒ, tʃ^h]-a (*ab-a etc.)	a[p]-t'a, a[k]-t'a a[t]-t'a	a[b]-ɨni, a[g]-ɨni a[s,t^h,dʒ, tʃ^h]-ɨni (*ad-ɨni)	a[m]-ni, a[ŋ]-ni a[n]-ni (*ab-ɨni etc.)
d. /al/	aɾ-a	al-da	a-ni (*aɾ-ɨ-ni)	a-ni (*aɾ-ɨ-ni)
e. /alɨ/	aɾ-a	aɾɨ-da	aɾ-ɨni	aɾɨ-ni
f. /al/	aɾ-a	at-t'a (*aɾ-ɨ-da)	aɾ-ɨni	an-ni (*aɾ-ɨ-ni)
g. /aw/	aw-a	ap-t'a (*aw-da)	au-ni (*aw-ni)	am-ni (*aw-ni)
h. /au/	aw-a (*au-a)	au-da	au-ni	au-ni
i. /aɾɨɾ/	aɾɨɾ-ə	aɾɨ-da (*aɾɨɾ-ɨ-da)	aɾɨ-ni (*aɾɨɾ-ɨ-ni)	aɾɨ-ni (*aɾɨɾ-ɨ-ni)
j. /all/	all-a	aɾɨ-da (*all-ɨ-da)	aɾɨ-ni (*all-ɨ-ni)	aɾɨ-ni (*all-ɨ-ni)

Considering that the two largest classes of Korean verbs are vowel-final stems and lateral-final stems, each of which exhibit vowel elision and l ~ ɾ alternations, it is not surprising that the model quickly learned the vowel elision and flapping.

While voicing alternations are underrepresented for some specific segments, such as [t], the large number of voicing alternations from other segments like /p/ or /k/ provide enough evidence to (wrongly) predict the voicing alternation for all obstruent-final stems at their very early stage. This is the tendency found in the learning of noun paradigms as well.

Inspection of the constraint weights reveals that OO-MAX -ɨ, OO-IDENT[±lat], and OO-IDENT[±voi] are the three output-to-output faithfulness constraints that are first demoted below their relevant markedness constraints. As in noun paradigms, coda neutralization is found from various segments, thus various segmental sources provide evidence to demote the relevant OO-Ident constraints relevant to coda neutralization. See the discussion in section 5.3 for the learning of coda neutralization.

5.4.3.3 Later-stage grammar

Next, when the σ^2 value was set to 100, mastery of w ~ p and ɾ ~ t alternations was found, and then the alternation of obstruents with nasals ((a) and (c) in the table below) were correctly predicted. The predicted patterns at this stage are given in (192). The following stage predicted by the model was the adult-like stage I presented in (190).

(192)

Stems in UR	-a/-ə	-ta (-Obs)	-ɨni (-ɨSon)	-ni (-N)
a. /ap/	ab-a	ap-ta	ab-ɨni	am-ni
b. /am/	am-a	am-t'a	am-ɨni	am-ni
c. /apʰ,ap'/, / akʰ,ak'/ / as,atʰ,adʒ,atʃʰ/	a[pʰ,p']-a, a[kʰ,k']-a a[s,tʰ,dʒ, tʃʰ]-a	a[p]-t'a, a[k]-t'a a[t]-t'a	a[b]-ɨni, a[g]-ɨni a[s,tʰ,dʒ, tʃʰ]-ɨni	a[m]-ni, a[ŋ]-ni a[n]-ni
d. /al/	aɾ-a	al-da	a-ni (*aɾɨ-ni)	a-ni (*aɾ-ɨ-ni)
e. /alɨ/	aɾ-a	aɾɨ-da	aɾ-ɨni	aɾɨ-ni
f. /al/	aɾ-a	at-t'a	aɾ-ɨni	an-ni (*aɾ-ɨ-ni)
g. /aw/	aw-a	ap-t'a	au-ni	am-ni (*au-ni)
h. /au/	aw-a	au-da	au-ni	au-ni
i. /aɾiɾ/	aɾiɾ-ə	aɾɨ-da (*aɾiɾ-ɨ-da)	aɾɨ-ni (*aɾiɾ-ɨ-ni)	aɾɨ-ni (*aɾiɾ-ɨ-ni)
j. /all/	all-a	aɾɨ-da (*all-ɨ-da)	aɾɨ-ni (*all-ɨ-ni)	aɾɨ-ni (*all-ɨ-ni)

This stage shows the opposite learning order from the experimental results, where we observed that children acquire nasal alternations earlier than w~ p and ɾ ~ t alternations. The contradictory learning order of the model is understandable when we consider that the featural changes involved in w ~ p and ɾ ~ t alternations are very general ones in the paradigms. Recall that I analyzed the w ~ p and ɾ ~ t alternations so that they incur violations of the faithfulness constraints for the feature continuant and the feature sonorant. The violations of IDENT(continuant) are found from coda neutralization and the violations of IDENT(sonorant) are found from nasal alternations, both of which are very frequent patterns in the paradigms. While w ~ p and ɾ ~ t alternations themselves are segmentally infrequent, the model easily learned their structural changes due to the fact that the featural components of the segmental alternations are general ones in the language. The speed of demoting the OO-Ident[±cont] and the OO-Ident[±son] constraints below the relevant markedness constraints was faster than the demotion of the OO-Ident[±nas] constraint, thus the wrong learning order was predicted.

Why then do children acquire w ~ p and ɾ ~ t alternations later than the frequency of constraint violations predicts, and why do they quickly acquire nasal alternations beyond what the frequency of constraint violations predicts? Additional source of learning nasal alternations could be a relevant factor. While w ~ p and ɾ ~ t alternations occur only within the verb paradigms, nasal alternations are found in the noun paradigms as well. The current simulations assumed distinct acquisition stages for noun and verb paradigms, so input data from each paradigm was fed separately for each simulation. In real life, however, children learn patterns of alternations from multiple sources. When an alternation is found in various paradigms within a language, the acquisition of the pattern will be facilitated.

It is also conceivable that the w ~ p and ɾ ~ t alternations involve additional feature changes which are not found from other alternations. The current analysis considered that the features continuant and sonorant are changed, but the w ~ p alternations involve change of the feature consonantal, and ɾ ~ t alternations involve change of the feature approximant. Since no other alternations show the change of consonantal and approximant features, the demotion of faithfulness constraints for the two features will be delayed; as a consequence, the learning of w ~ p and ɾ ~ t alternations which involve infrequent featural changes, will be delayed as well. I tried an additional simulation including the additional features approximant and consonantal, and it indeed hindered the learning of w ~ p and ɾ ~ t alternations. However, this resulted in no learning of the two alternations; OO-Ident [consonantal] and OO-Ident[approximant] constraints were barely demoted even at the adult stage. Recall that w ~ p and ɾ ~ t alternations were correctly produced in stages earlier than when children produce forms involving the deletion of lateral, as the attested acquisition stages in (171) show. Thus it seems reasonable that learners consider the w ~ p and ɾ ~ t alternations as shared structural changes –i.e., change of the sonorant and continuant features, and the patterns are acquired relatively later than what the constraint violations within the verb paradigms predict.

5.5 Summary & Discussion

The learning trajectory of Korean noun and verb paradigms was simulated using Maximum Entropy grammar learning with weighted constraints. Pieces of the model were the initial bias on OO-IDENT constraints and constraint demotion according to the frequency of its violations. The model predicted the dominant production patterns in each learning stage, in the process of adjusting the weights of the constraints. The success of the biased model's learning provides empirical support for the OO-CORR bias, together with the elicited production patterns from child learners in § 2.

One might raise the possibility of reanalyzing the results in terms of incorrect underlying representations (URs) instead of OO Faithfulness constraints. Imagine that children wrongly map URs, and that the forms of URs are different in different developmental stages. Take coronal obstruent-final nouns as an example. If the stem-final segment of every coronal obstruent-final noun is /-t/ at this stage, their predominant production of [-t] can be interpreted as the faithful realization of inputs. At a later stage, if the stem-final segment of coronal obstruent-final nouns is assumed to be /-s/, the tendency that oldest children overwhelmingly produced coronal obstruent-final nouns as [-s] can be understood as the faithful realization of the input as well. If so, we might simulate the learning by changing URs and get similar results.

In spite of its potential to succeed in learning, we do not find an empirical reason to believe that /-t/ is a UR of every coronal obstruent-final nouns in the early stages and is changed as /-s/ in the later stages. The analysis based on the initial OO-CORR bias, however, can provide a complete package of each of the stages, and it does account for why one follows the other: during the process of demoting OO-IDENT constraints, the model predicted the attested progression of learning stages. Thus, even though there could be an alternative way for the model to succeed in learning Korean noun and verb paradigms, I claim that the current analysis relying on the initial OO-CORR bias is a more insightful and reliable account for the acquisition of patterns of alternations.

6 Natural classes and learning alternations[22]

A remarkable aspect of the child data in the current study is that children produce alternating forms that are never found in the adult language. For instance, I found that Korean-learning children inflect coronal obstruent-final nouns by alternating [t] with [d] in intersonorant position, which is not attested within Korean noun paradigms, according to an adult corpus data of inflected nouns (Kang and Kim 2004). How do children in early developmental stages produce alternations that are not predicted to be learned early (or at all) simply according to their frequency?

Despite the lack of specific alternations at the segment-level, the innovative forms involve featural changes that are fully general in noun paradigms: the alternation found in [t] ~ [d] involves the voicing alternation which is productive in Korean noun paradigms, as the examples in (193) show. This observation leads us to the hypothesis that children innovate inflected noun forms involving [t] ~ [d] alternations, because the acquisition of [t]~[d] alternations is facilitated by featurally parallel segmental alternations such as [p]~[b] and [k]~[g].

(193) Voicing alternations in noun paradigms

[t] ~ [d]	[p] ~ [b]	[k] ~ [g]
	/pap-i/ → [pabi] 'rice-Nom'	/mak-e/ → [mage] 'slide-Loc'

Children's production of [t] ~ [d] alternations in noun inflection could also be motivated by the fact that the segmental [t] ~ [d] alternations are seen frequently in a broader range of contexts in the language as a whole. Because the alternation is motivated by a general phonotactic restriction (i.e., intersonorant voicing), it is not only found at the end of noun stems, but also at the end of verb stems, within morphemes, in compounds, and even across phrasal boundaries, as shown in the examples in (194). Given the high segmental frequency of [t] ~ [d] alternations in a wide range of contexts, it is plausible to hypothesize that children generalize the segmental [t] ~ [d] alternations from other contexts to noun inflection.

[22] The project in this chapter was conducted with Adam Albright.

(194) Voicing alternations in various contexts

Monomorphemes	/kjetan/→ [kjedan] 'stairs'
Noun inflections	
Verb inflections	/tat-a/ → [tada] 'close-Imp'
Compounds	/mat-atil/ → [madadil] 'first son'
Phrasal boundaries	/kot owajo/ → [kodowajo] 'soon come'

Chapter 2 reported a similar pattern from the production study of Korean verb inflection. Stem-final aspirated voiceless obstruents /p^h/, /t^h/ and /k^h/ are expected to alternate with their lenis counterparts [p], [t] and [k], as required by the Korean phonotactic principle of coda neutralization, but the type frequencies of such alternations are relatively low in Korean verb paradigms–i.e., 0.4% of entire verb alternations in the Sejong Corpus of written Korean. However, child participants successfully produced the forms involving /p^h/ ~ [p], /t^h/ ~ [t], and /k^h/ ~ [k] alternations, while at the same acquisition stages they failed to produce more frequent segmental alternations, such as [w] ~ [u] (12% of verb alternations), [ll] ~ [ɾ] (8%) and [ɾ] ~ [t] (2%) alternations.

In Chapter 4, learning simulations trained on the Korean corpus showed that the attested child production patterns, such as stem-final [t] ~ [d] alternations in nouns and the coda neutralization of aspirated obstruents in verbs, emerged in intermediate learning stages. The reason for this outcome is that the model learned the shared structure of individual segmental alternations and learned the alternations at the featural-level. For instance, the model quickly learned voicing alternations from [p] ~ [b] and [k] ~ [g] alternations, both of which are very frequent in Korean, and this evidence facilitated the learning of [t] ~ [d] alternations, which are segmentally infrequent. For [p^h] ~ [p], [t^h] ~ [t], and [k^h] ~ [k] alternations, the model found a large number of data showing coda neutralization in Korean, and it generalized the processes to the aspirated voiceless obstruent-final items, which are segmentally infrequent in nouns.

Both factors, segmental frequency and featural frequency of alternations, are a priori plausible and the question is what the specific contribution of each factor is in learning phonological alternations.

A variety of studies have shown results that indicate the role of featural structure in learning alternations. For example, learners find it easier to learn processes that affect a natural class of segments than a non-natural class of segments (Wilson 2006, Moreton 2008, Finley & Badecker 2009, Hayes et al. 2009, Becker et al. 2011, Skoruppa et al. 2011). Also the learning of processes that can be decomposed into a set of independent featural alternations proved to be better than those that affect only a combination of feature values without affecting those values independently (Moreton 2008, Pater & Moreton 2011, Finley 2008, White & Sundara 2012). This could lead us to conclude that there is good reason to think that learners are sensitive to whether or not a process affects a shared structure of alternations. In spite of these theoretical and empirical considerations, no previous studies have tested the question of how narrower (e.g., segment-level alternations) and broader natural classes (e.g., feature-level alternations) contribute to the generalization of alternation patterns, where multiple classes are compatible with the data.

To illustrate this question with a simple example, to what extent is a datum like [at] ~ [ada] taken as evidence for learning [t] ~ [d] alternations vs. for voicing alternations in general? In order to answer this question, we need to test learners' preference for different alternations in a language where narrower segment-level and broader feature-level preferences conflict with each other. An artificially controlled setting is necessary here, in which only the segment-level and feature-level preferences differ without varying any other linguistic factors. We employ artificial grammar learning paradigms, and show that featural overlap facilitates the learning of alternations. It is also shown that the degree of the facilitation is different depending on different features. We attribute the results to the perceptual bias (Steriade 2001) that learners are more reluctant to change perceptually more salient features. Based on the experimental data, we propose a learning model that builds in the featural generalizations and the perceptual bias.

6.1 Featural overlap facilitates learning alternations

Consider the mini language in (195). This language presents four crucial properties that are relevant to the feature-based and the segment-based generalizations. First, the language has more stems ending in coronals than labials: 16 coronal alternations vs. 9 labial alternations. Second, in the language as a whole, voicing alternates more than continuancy: 16 stems alternate in voicing vs. 9 stems alternate in continuancy. Third, among coronals, the general featural preference is mirrored at the segmental level as well: 13 voicing alternations vs. 3 continuancy alternations. Fourth, among labials, the featurally more frequent alternation in the language, the voicing alternation, is segmentally less frequent: 3 voicing alternations vs. 6 continuancy alternations.

(195) A hypothetical mini-language

	Labial		Coronal		Total
Voicing	p~b	3	t~d	13	16
Continuancy	p~f	6	t~s	3	9

Suppose a grammar is composed of faithfulness constraints for voicing (OO-Ident([±voi])) and continuancy (OO-Ident([±cont])), and markedness constraints barring voiceless non-continuant coronal (*VtV) and voiceless non-continuant labial (*VpV) in intervocalic positions. We describe broader structure in faithfulness constraints and more specific structure in markedness constraints, following the convention in the OT literature to state faithfulness constraints on features independently, while markedness constraints often refer to co-occurring feature values. However, it is equally fine to assume the opposite division of the labor between faithfulness constraints and markedness constraints (i.e., broader markedness constraints and more specific faithfulness constraints). We discuss the ways of encoding different structures in different constraints later in section 6.5.

In gradual learning grammars assuming numeric weighting (e.g., GLA: Boersma 1997, Magri 2012, or Stochastic Gradient Ascent Jäger 2007), constraints are weighted along a numeric scale. Learners gradually decrease values for loser-preferring constraints and increase values for winner-preferring constraints.

Suppose data about alternations trigger updates to constraint weights, hypothetically after hearing each word once and adjusting values by ±1. Also suppose the initial weight of the faithfulness constraints is 100 and that of the markedness constraints is 80. The alternations in the mini-language in (195) cause the updates to constraint weights as shown in (196).

(196) Learning by alternation data in (195)

Constraint	Relevant alternations	Initial value	Updates	Intermediate value
OO-Ident([±voi])	p~b, t~d	100	−16	84
OO-Ident([±cont])	p~f, t~s	100	−9	91
*VtV	t~d, t~s	80	+16	96
*VpV	p~b, p~f	80	+9	89

Due to a greater number of voicing alternations in the language as a whole, the OO-Ident(voi) constraint is demoted faster than the OO-Ident(cont) constraint. This predicts that voicing alternations are preferred regardless of place, as in (197). Because learners find more evidence to support the *VtV constraint than the *VpV constraint in this language, the *VtV is promoted faster than the *VpV. Therefore, alternations will be in general preferred for coronals. In (197), the continuancy alternations are predicted for coronals due to the constraint ranking *VtV over OO-Ident([±cont]), but no continuancy alternations are predicted for labials since the OO-Ident([±cont]) still outranks the *VpV. These considerations imply that exposure to one alternation contributes to the learning of featurally overlapping alternations by triggering adjustments to weights needed to produce them.

(197) The prediction of the trained grammar

	*VtV 96	OO-Ident([±cont]) 91	*VpV 89	OO-Ident([±voi]) 84
/foʊt-i/				
a. foʊti	*			
☞b. foʊdi				*
c. foʊsi		*		
/seɪp-i/				
a. seɪpi			*	
☞b. seɪbi				*
c. seifi		*		

We tested (a) whether the speed of learning a segmental alternation depends not only on the specific frequency of that segmental alternation but also on the total frequency of all pairs sharing the same featural change, and (b) how segment-level and feature-level evidence contribute to learning patterns of alternation.

6.1.1 Experimental testing

6.1.1.1 Design

The strategy was to create an artificial language exhibiting alternations with different frequencies, to expose participants to the language, and then to test their preferences for certain alternations over others. We set up the language in (195), in which feature-level and segment-level frequencies conflict with each other.

Testing which alternations participants prefer among labials allows us to explore whether the learning of the segmentally less frequent alternation is facilitated by the featurally more frequent alternation or not. If learners find evidence for learning the *p* ~ *b* alternation not only from *p* ~ *b* but also from *t* ~ *d*, and evidence for learning *p* ~ *f* alternation not only from *p* ~ *f* but also from *t* ~ *s*, the prediction is as follows: learning segmentally less frequent alternations (e.g., *p* ~ *b*), should be facilitated, due to featural overlap with the frequent alternations (e.g, *t* ~ *d*). Also, if participants have the bias for OO-Faithfulness constraints as observed from the experimental studies in Chapter 2, and if they detect the difference of segmental frequencies of alternations, a greater rate of non-alternation will be found for labials, since alternations shown for labials are less frequent in the training data. The two predictions of this experiment are summarized in (198).

(198) Predictions

a. The less frequent labial alternation (*p* ~ *b*) should be facilitated, due to featural overlap with the frequent coronal alternations

b. A greater rate of non-alternation will be observed for labials than for coronals, since alternations are seen less for labials in training.

The artificial language we constructed showed singular and plural pairs of nonce words, exhibiting stem-final consonant alternations. Twenty-five alternating items were presented as in (199), with type frequencies of alternations in (195). Items were either monosyllabic or disyllabic stems, with stem-initial stress on disyllabic items. Segments were chosen to roughly control for the overall frequency of segments that exhibit alternations: 17 *f*, 15 *b*, 16 *d*, and 14 *s*. Twenty sonorant-final fillers were also included, which did not exhibit alternations.

(199) Items in the artificial language

	Labial	Coronal
Voicing	dap fɹu:p seɪp	bri:t fleɪt bi:loʊt flat skoʊt foʊmat slu:t peɪt beɪnut pɹut smi:t foʊt klu:t
Continuancy	boʊp bru:p ski:p figap bɹeɪp bamu:p	blu:t pɹat bɹoʊt
Segment frequencies in plural forms, including fillers: 17 *f*, 15 *b*, 16 *d*, 14 *s*		

Words of the language were represented orthographically as in (200), as well as auditorily. Participants learned the system of orthography before they entered the training session. After they were given instructions about the system of orthography, participants were asked to listen to several nouns in frame sentences to show how the orthography was applied to actual items.

(200) The system of orthography

[i] = *ee*, [eɪ] = *aC(e)*, [a] = *ah*, [oʊ] = *oC(e)*, [u] = *oo*
E.g., [snoʊl] *snole*, [bamup] *bahmoop*, [pɹeɪni] = *pranee*
Frame: This is a *bahmoop*.

Participants were given an implicit learning task. The explicit task was to learn to form plurals in a Martian language. They were instructed to pay attention to the quality of suffix vowel. An example item provided in the instructions is illustrated in (201).

(201) Explicit task

"Just like in English, Martian nouns have a special ending to indicate the plural. Sometimes this ending is pronounced *-ee*, and sometimes it is pronounced *–oo*. For example,"

This is a [flim]. 

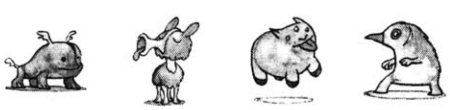
These are [flimi]. 

Vowel quality was determined by height-conditioned rounding harmony with the preceding vowel: [u] after [u], and [i] elsewhere. For instance, san ~ san**i**, preɪn ~ preɪn**i**, snoʊl ~ snoʊl**i**, flim ~ flim**i**, and drun ~ dr**unu** were correct plural forms in the Martian language, according to the vowel harmony rule assumed in the explicit task. Participants were not shown any instance exhibiting consonant alternation in the instructions. By using an implicit learning paradigm, we expected to draw participants' attention away from consonant alternations, hopefully reducing task-specific strategies for learning consonantal alternations.

6.1.1.2 Training

A web-based experiment was conducted, using Experigen (Becker and Levine 2010). Martian creatures as in (202) (Van de Vijver and Baer-Henney 2011) were paired with names, randomly for each participant.

(202) Martian creatures



Participants heard and saw a pair of singular and plural names for each creature. Auditory stimuli were produced by an English/Arabic bilingual male speaker. Since the speaker did not apply glottalization or flapping of coronals in the recordings, all stimuli exhibiting the [t] ~ [d] alternation in orthography were correctly pronounced as [t] ~ [d]. All singulars were always presented auditorily as well as orthographically, but plurals were presented auditorily, with or without orthography. We randomly selected half of the training items, and left a blank in a written frame sentence, such as "*These are* __________". Participants were asked to type the plural form that they had just heard, with feedback. We included this test to ensure that participants pay attention to the test. All items and fillers were presented once per a participant in randomized order. Participants were able to listen to names as many times as desired before moving on to the next pair of items.

6.1.1.3 Test

The test session presented two types of tests: a familiarity test and a generalization test. In the familiarity test, participants were presented with singular and plural pairs, and asked if a word was in the language. Nine trained obstruent-final items were shown, with alternations as presented in the training session. Twelve untrained obstruent-final items were also presented, half of which exhibit a voicing alternation and the other half exhibited a continuancy alternation. Since every item was presented only once in the training session, and participants were exposed to 45 items, including fillers, during the experiment, it is not realistic to expect that they memorized individual items. Thus, we did not expect a consistent preference for trained items over untrained items. Rather, the main interest of the familiarity test was the comparison between their preferences for one alternation over the other. To check how successful participants were on the explicit task, fifteen trained sonorant-final filler items were included in familiarity test as well. Seven items out of 15 showed correct height-conditioned rounding vowel harmony, 5 items showed incorrect vowel harmony (i.e., [i] after [u], and [u] elsewhere), and 3 items showed an unseen suffix, [a]. Subjects responded if these stimuli were words in the language or not.

In the generalization test, participants were presented with a novel (untrained) obstruent-final singular item, and asked which form they preferred for the plural. Eight test items were presented, 4 coronal-final and 4 labial-final ones. They were disyllabic stems with stem-final stress. The stem-final stress was chosen intentionally, so that items sounded different from trained items, which had stem-initial stress. Novel singular forms were presented auditorily and orthographically, and participants were given three possible plural choices in orthography: no alternation, the voicing alternation, or the continuancy alternation. They were asked to tell what the Martian plural would be, in forms of a forced choice test as the example in (203) shows.

(203) A generalization test

"Tell us what you think the most likely plural form would be."
Singular: [goʊseɪp]
Choices of plural: [goʊseɪpi], [goʊseɪbi], [goʊseɪfi]

Three of untrained sonorant-final items were also included in the generalization test as controls, which enabled us to check whether participants had learned the height-conditioned rounding vowel harmony patterns and generalize this knowledge. Answer choices presented plurals containing correct vowel harmony, a disharmonic pattern and an unseen stem change, as in (204).

(204) Controls to check the generalization of vowel harmony

	Correct	Disharmonic	Unseen stem change
[sleɪm]	[sleɪmi]	[sleɪmu]	[slumu]
[blun]	[blunu]	[bluni]	[blini]
[plor]	[plori]	[ploru]	[plosi]

6.1.1.4 Participants

Eighty participants who self-reported as native English speakers were recruited from U.S. IP address via Amazon Mechanical Turk. Mean time of participation was 17 minutes (median = 15, min = 8, max = 41). Each person was paid $1 for participation. We discarded participants who did not complete the task or who mistyped at least one of the attention questions, in which they were asked to type the plural form that was presented auditorily. This left 58 participants, whose results we analyzed.

6.1.1.5 Results

The learning of vowel harmony was checked by the familiarity test as well as by the generalization test. We compared participants' choices in the familiarity test, where they were asked whether a word was in the language. Items exhibiting three patterns of vowel harmony were presented: items showing correct harmony (i.e., [-u] after stem-final [u], [-i] elsewhere), incorrect harmony (i.e., [-i] after stem-final [u], [-u] elsewhere), and a completely novel suffix (i.e., [-a]), which was never seen in the training session. The acceptance rate of each choice is presented in the table (205).

(205) The acceptance rate of vowel harmony in the familiarity test

	Correct harmony	Incorrect harmony	Unseen suffix
-i	58.2%	25.9%	4.6%
-u	66.7%	31.0%	

As shown in (205), participants accepted the correct harmony at higher rates than the incorrect harmony, and they did not accept the unseen suffix for most of the cases. This result is evidence that participants paid attention to the explicit task and were generally able to learn height-conditioned rounding harmony. A similar result was found in the generalization test. Here, participants were asked to choose the preferred plural form of a given singular form from among the three choices showing the correct harmony pattern, the disharmonic pattern, and the unseen stem change (i.e, [r] ~ [s]). The table in (206) shows the percentage of participants' choices for each option.

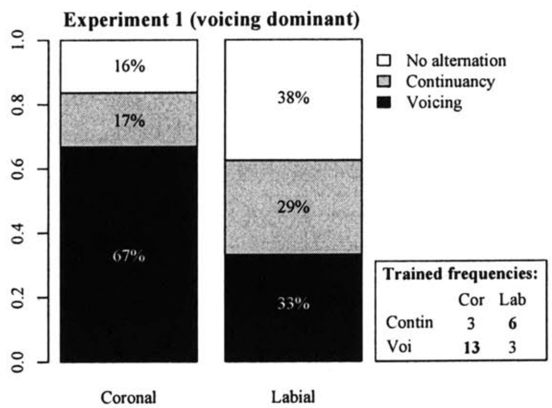
(206) The preference among correct harmony, disharmony, and unseen stem change

	Correct harmony	Disharmonic	Unseen stem change
blun	88%	10%	2%
sleɪm	90%	9%	2%
plor	64%	21%	16%

Participants highly preferred the correct harmony to the disharmonic choice for all three items. The rate of choosing the unseen stem change was lowest. Together with the result of the familiarity test in (205), the result of the generalization test in (206) confirmed that participants generally the learned height-conditioned vowel harmony. We take this as evidence that they focused on the task.

Recall the predictions for the implicit task of learning consonant alternations. We expected a greater rate of non-alternation for labials, since alternations were seen less frequently for labials than for coronals in the training data. The reason for this prediction is that the *VpV constraint should be promoted less than the *VtV constraint, relative to the amount that the OO-Ident ([±voice]) constraint is demoted. We also expected a general preference for voicing alternations, since these were more frequent than continuancy alternations in the language as a whole. This prediction follows from the hypothesis that the OO-Ident ([±voice]) constraint will be demoted faster than the OO-Ident([±continuancy]) constraint, due to the greater frequency of violations in the artificial language. The result of the test is given in the graph in (207).

(207) Participants' preference for consonant alternations in the generalization test



As the comparison of the white portions of the two bars shows, participants preferred no alternation more among labials (38%) than coronals (16%). This result can be derived when a coronal markedness constraint (*VtV) is promoted relative to high-ranking OO-Ident constraints more than a labial markedness constraint (*VpV), due to the frequent alternations seen among coronals in this language. As the comparison between the gray and black portions in each bar shows, participants preferred voicing alternations to continuancy alternations, not only among coronals but also among labials. The preference, though, is relatively slight, but what is important at the moment is that participants did not prefer the more frequent *p~f* alternations.

Given that voicing alternations were less frequent than continuancy alternations among labials in the training data, the current result supports the hypothesis that there is a facilitation learning effect from coronals: the high frequency of *t* ~ *d* voicing alternations encouraged *p* ~ *b* alternations, even though the trained frequency of *p* ~ *b* alternations was lower than that of *p* ~ *f* alternations. What is not predicted, but observed from the current test, is a greater preference for voicing specifically among coronals: as the larger black portion of the bar for coronals than labials indicates, participants preferred voicing alternations far more for coronals than for labials. This result mirrors the greater segmental frequency of *t* ~ *d* alternation.

To test the statistical significance of the results, we ran a mixed effects logistic regression, using lme4 (Bates, Maechler and Dai 2012). Participants had a three-way choice, no alternation, voicing alternation and continuancy alternation. While modeling the three-way choice requires multinomial logistic regression, there is currently no available package for fitting mixed effects multinomial logistic regression models in R. Thus, we focused specifically on the binary choice of continuancy alternations and voicing alternations. In this model, the intercept reflects the overall preference for voicing over continuancy alternations. Place was entered as a sum-coded factor, to test whether participants preferred voicing alternations specifically among coronals. A random intercept was included for items, and a random intercept and a random slope for place were included for participants. The result is given in the table in (208).

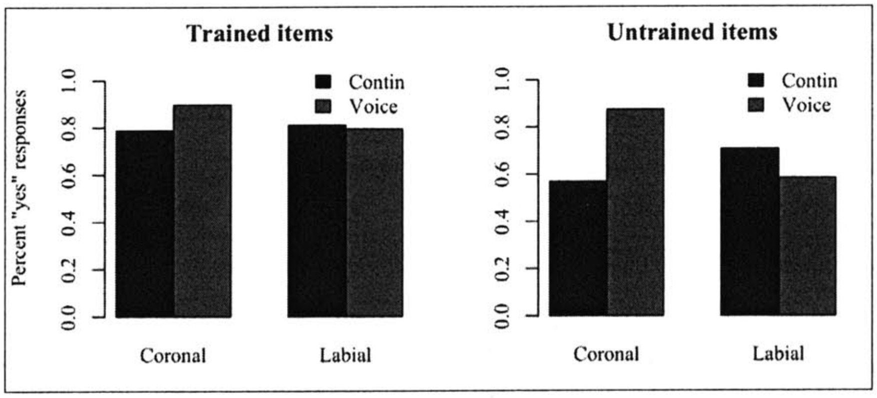
(208) The generalization test result from mixed effects logistic regression

Experiment 1	Estimate	Std. Error	z value	Pr(>|z|)
Intercept (*voicing*)	1.7710	0.3670	4.825	<.0001 ***
Place (*coronal*)	1.3256	0.3277	4.045	<.0001 ***

As the statistical significance of the intercept shows, a significant overall preference for voicing alternations was found. This result indicates that frequent *t* ~ *d* alternations facilitated segmentally infrequent *p* ~ *b* alternations, which share the same featural changes with *t* ~ *d* alternations. The result is predicted by greater demotion of the OO-Ident([±voice]) constraint, relative to the OO-Ident([±continuancy]) constraint. The significantly positive coefficient for the place factor shows that voicing alternations are significantly more preferred among coronals (*t* ~ *d*) than among labials (*p* ~ *b*). This result is not predicted by the relative ranking of the OO-Ident([±voice]) constraint with respect to the *VtV constraint and the *VpV constraints. Rather, this shows that participants detected different segmental frequencies between *t* ~ *d* and *p* ~ *b*, and generalized the knowledge when they were faced with novel items.

In the familiarity task, participants were asked whether a pair of words had been presented in the language. Both trained items and untrained items were included in the test items. If there was a facilitation learning effect, we expect a higher acceptance rate for voicing alternations than for continuancy alternations both for trained and untrained items, because in the language as a whole the voicing feature alternates more frequently. The result is illustrated in the graph in (209).

(209) Participants' acceptance of consonant alternations in familiarity task



Trained frequencies:		
	Cor.	Lab.
Contin.	3	6
Voice	13	3

As illustrated in (209), participants preferred voicing alternations specifically for coronals both for trained and untrained items. However, unlike the result of the generalization task, no systematic preference for voicing alternations seems to be observed. Instead, a preference for more frequent segmental alternations, *t* ~ *d* over *t* ~ *s* and *p* ~ *f* over *p* ~ *b*, was found.

We assessed the statistical significance of the result by a mixed effects logistic regression model, using lme4. The full model assuming three-way slopes for types of alternation (voicing vs. continuancy), place (coronal vs. labial) and training effect (trained vs. untrained) did not converge. A straightforward option is to take away some of the random slopes (e.g., two-way slopes for types of alternations), but some of the main effects such as alternation or place went away. The problem may be due to the fact that some participants strongly prefer either 'yes' or 'no' answers regardless of questions. Also another reason why the model had difficulty converging may be that there is a limited amount of data in the experiment. Once we ran the model including the results of this experiment together with the result of the following experiment in the following section 6.2, the model successfully converged. Thus, we report the result of the two familiarity tests together in section 6.3.

6.1.2 Discussion

The generalization test bears out the key predictions. The learning of a segmental alternation was facilitated by the alternations with featurally overlapping constraint violations. For instance, the learning of *p*~ *b* alternations was facilitated by the learning of *t* ~ *d* alternations, leading to the overall preference for the voicing alternations, which was predicted by the shared OO-Ident constraint violations. Participants also preferred more frequent segmental alternations –i.e., *p~f* over *p~b* and *t~d* over *t~s,* indicating that learners are detecting the frequency difference of individual segments in learning patterns of alternation.

It is worth pointing out, however, that all of the observed participants' preferences have been attributed to the greater frequency in the training data. Voicing alternations are preferred to continuancy alternations due to the higher frequency of voicing alternations overall, and segmentally *t* ~ *d* is preferred to *p* ~ *b* due to the higher segmental frequency of coronals than labials.

These results are compatible with learning based on the frequency of segments and also alternations, but we cannot actually be sure that participants really learned voicing among labials on the basis of coronals. Possibly, participants just like voicing alternations better than continuancy alternations, so training on 6 *p~f* items and 3 *p~b* alternations simply leads them to favor *p~b* alternations. This possibility is not so far-fetched. In fact, Kaplan (2010) found cross-linguistic preference to lenite intersonorant voiceless coronal obstruent by voicing rather than spirantization. Asymmetry is weak or inconsistent across different perception tests (cf. Schmidt-Nielsen 1983; Kaplan 2010, §4.3), but, as far as we know, never reversed in clear speech. Based on this observation, we hypothesize that perceptually voicing alternations are less salient than continuancy alternations, and voicing alternations with short closure (*t* ~ *d*) could also be less salient than voicing alternations with medium closer (*p* ~ *b*).

Given that the preferred patterns, both at the featural and at the segmental levels, are perceptually less salient alternations, the results in Experiment 1 may not simply be due to the frequency effect, but rather perceptual biases might have facilitated the learning of perceptually less salient alternations over more salient ones. In order to disentangle the role of perceptual biases from the frequency effect in learning alternations, we need to switch the frequencies of voicing and continuancy alternations, so that more frequent alternations are perceptually more dissimilar. The main focus here is to see if participants' preference for more frequent alternations would be robust despite perceptual dissimilarity, of if their preference is weakened due to perceptual biases.

In the example in (226), the P-Map hypothesis predicts higher weights for the OO-Ident([±cont]) constraint than for the OO-Ident([±voi]) constraint, under the hypothesis that perceptually the change of the continuancy feature is more salient than the change of the voicing feature, thus learners could be more reluctant to change continuancy of a segment. If such perceptual bias is a mechanism found in learning alternations, we may see a different amount of facilitation for different features. This leads us to the following prediction:

(210) Prediction of Experiment 2

If the perceptual distance between [+F] and [-F] is greater than that between [+G] and [-G] then the constraint Ident F will be demoted slower than Ident G.

6.2 Perceptual bias facilitates learning alternations

Consider the artificial language in (211). As in Experiment 1, the language has more stems ending in coronals than labials. Also like Experiment 1, the general featural preference is mirrored at the segmental level among coronals. In the language as a whole, continuancy alternations are more frequent than voicing alternations. This is the opposite situation from Experiment 1. Among labials, the featurally more frequent alternations in the language, continuancy alternations, are segmentally less frequent. While both experiments exhibit the conflict between the segment-level and the feature-level frequencies, in Experiment 2, the featurally more frequent alternations among labials, *p ~ f*, are hypothesized to be perceptually dispreferred, as opposed to Experiment 1; in Experiment 1, the featurally more frequent alternations among labials, *p ~ b*, are perceptually preferred as well.

(211) An artificial language

	Labial		Coronal		Total
Voicing	p~b	6	t~d	3	9
Continuancy	p~f	3	t~s	13	16

Data about alternations trigger updates to constraint weights. Assuming a perceptual bias that learners are more hesitant to apply continuancy alternations to a segment (the more salient change) than the voicing of a segment (the less salient change), let us suppose that the learners adjust values for the OO-Ident([±voi]) constraint by -1 when they hear each word exhibiting voicing alternations, while they adjust the values for the OO-Ident([±cont]) constraint by -0.5, when faced with each word showing continuancy alternations. As before, the adjustment value of all markedness constraints is assumed to be +1. If the initial weight of the faithfulness constraints is 100, and that of the markedness constraints is 80, the learner will acquire the grammar presented in (212) after learning the patterns.

(212) The trained grammar

Constraint	Relevant alternations	Initial value	Updates	Intermediate value
OO-Ident([±voi])	p~b, t~d	100	−9	91
OO-Ident([±cont])	p~f, t~s	100	−8	92
*VtV	t~d, t~s	80	+16	96
*VpV	p~b, p~f	80	+9	89

Since the faithfulness constraints for voicing as well as for continuancy are demoted below *VtV, voicing alternations and continuancy alternations are predicted for coronals, as the grammar in (213) shows. While the language exhibits more continuancy alternations than voicing alternations, no continuancy alternations are predicted for labials, because the OO-Ident([±cont]) constraint is not fully demoted below *VpV due to the initial bias assumed on OO-Ident([±cont]). This predicts that a perceptually more salient alternation may not be generalized as readily as a perceptually less salient alternation.

(213) A biased learner vs. an unbiased learner

	*VtV 96	OO-Ident([±cont]) 92	OO-Ident([±voi]) 91	*VpV 89
/foʊt-i/				
a. foʊti	*			
☞b. foʊdi			*	
c. foʊsi		*		
/seɪp-i/				
a. seɪpi				*
☞b. seɪbi			*	
c. seɪfi		*		

We tested whether the perceptual bias is a mechanism in generalizing alternation patterns.

6.2.1 Experimental testing

We switched the frequencies of the voicing and continuancy alternations, so that this time the perceptually more dissimilar alternation is more frequent. The conflicting preferences between feature-level and segment-level frequencies are presented in (214), compared to the setting of Experiment 1 on the right-side.

(214) Design of Experiment 2

Exp 2: Contin.	Labial	Coronal	Total
Voicing	p~b 6	t~d 3	9
Continuancy	p~f 3	t~s 13	16

Exp 1: Voicing	Labial	Coronal	Total
Voicing	p~b 3	t~d 13	16
Continuancy	p~f 6	t~s 3	9

The set of the training items presenting the alternations in (214) is given in (215).

(215) Training items in Experiment 2

Experiment 2	Labial	Coronal
Voicing	dap famu:p fɹu:p dɹi:p bleɪp fɹeɪp	dɹoʊt danu:t foʊt
Continuancy	boʊp flu:p digap	blu:t flat beɪnu:t pɹat foʊmat peɪt bɹoʊt biloʊt pru:t fleɪt smi:t bɹi:t klu:t
Segment frequencies in plural forms, including fillers: 17 f, 17 b, 17 d, 16 s		

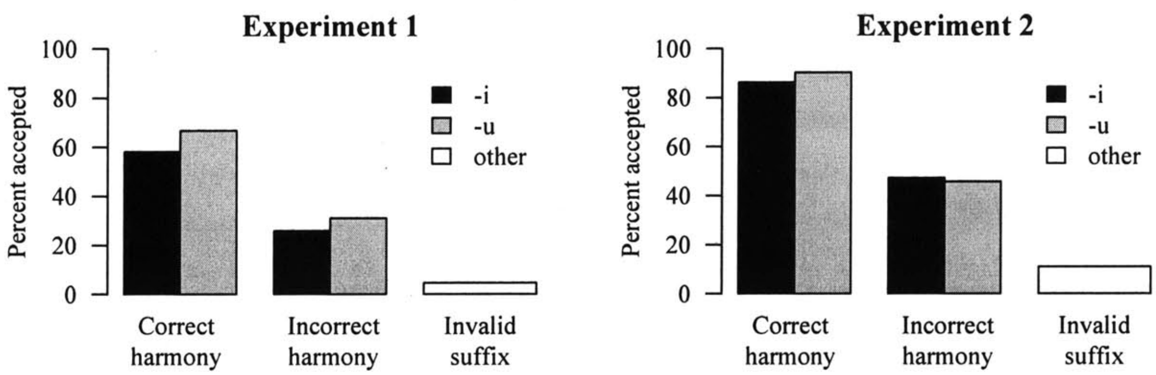
6.2.1.1 Design, Training, Test & Participants

The pairs of singular and plural nonce words exhibited stem-final consonant alternations. Type frequencies of the alternations in the language were shown in (214). The segmental frequencies of *b, d, f,* and *s*, were controlled to be equal overall. Twenty sonorant-final fillers which do not present alternations were included. The same implicit learning paradigm used in Experiment 1 was employed again (see § 6.1.1.1). The processes of training and testing were the same as Experiment 1, except that the success of learning height-conditioned rounding vowel harmony was tested only in forms of the familiarity task, but not the generalization task (see § 6.1.1.3 for the comparison). Participants were recruited from U.S. IP address via Mechanical Turk, and each participant was paid $1 for participation. Mean time of the participation was 17 minutes (media= 21, min = 8, max= 41). According to the same criterion we used in Experiment 1, we distinguished the attentive participants (see §6.1.1.4); out of 90 participants, this left 48 whose responses were entered into the analysis.

6.2.1.2 Results

Twelve items exhibited the correct vowel harmony (i.e., [-u] after stem-final [u], [-i] elsewhere), the incorrect vowel harmony (i.e., [-i] after stem-final [u], and [-u] elsewhere), and a completely novel suffix which was never seen in the training data (i.e., [-a]). Participants were asked if words showing one of the three vowel harmony patterns were in the language. The result is illustrated in (216), compared to the result of Experiment 1.

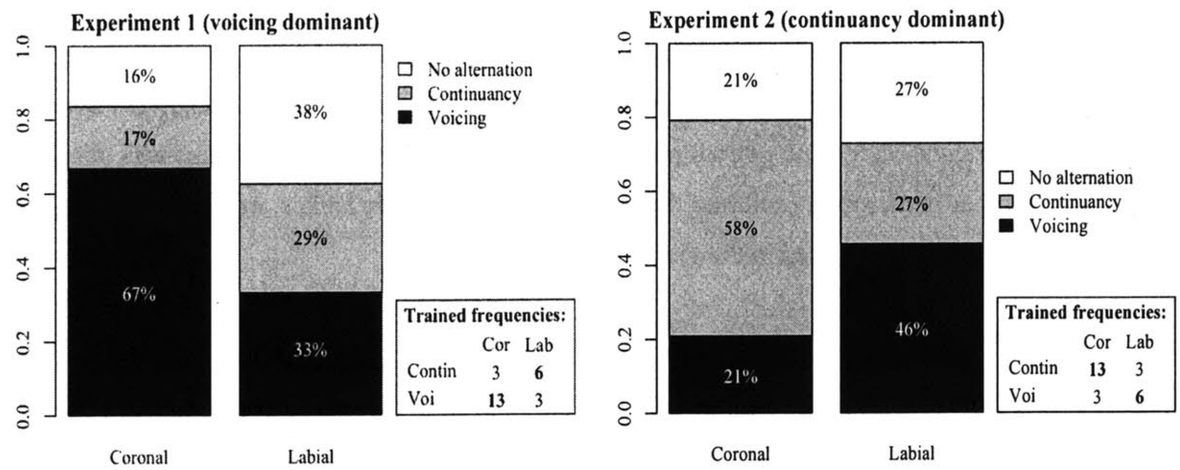
(216) The result of the explicit task



As in Experiment 1, participants almost always rejected the invalid suffix. They systematically accepted the items showing the correct harmony at higher rates than those showing the incorrect harmony. The overall acceptance rate was higher in Experiment 2 than Experiment 1, but the tendency to accept the correct harmony over the incorrect harmony or the invalid suffix was retained. We took this as the evidence that participants paid attention to the test.

Recall our two main predictions of the implicit task. First, we predicted a greater rate of non-alternation for labials, since labials were less frequent in the training data. Second, the general preference for the continuancy alternations was predicted, because these alternations were more frequent overall in the language than the voicing alternations. Crucially, we also predicted that the preference for the continuancy alternations would not be as strong as the preference for the voicing alternations observed in Experiment 1, since the continuancy alternations are perceptually dispreferred. The results are illustrated in (217), compared to the results of Experiment 1.

(217) The results of the generalization task



Like in Experiment 1, more non-alternation was observed for labials (27%) than for coronals (21%). A preference for the continuancy alternations specifically among coronals was observed (58% for continuancy vs. 21% for voicing), mirroring the higher trained frequency of *t* ~ *s*. Unlike Experiment 1, there was no strong overall preference for the continuancy alternations. Among labials, participants preferred the voicing alternations (46% for voicing vs. 27% for continuancy), which mirrors the higher segmental frequency of *p* ~ *b* than *p* ~ *f*. This result indicates that there is no strong facilitation learning effect of the continuancy alternations. It is a remarkable difference from the result of Experiment 1, from which we found a strong facilitation learning effect of the voicing alternations on labials.

The statistical significance of the results was assessed by a mixed effects logistic regression model. The same factors and their interactions were entered as in Experiment 1 (see §6.1.1.5), but for Experiment 2, the overall preference for the continuancy alternations was included as the intercept. The result is given in the table in (218).

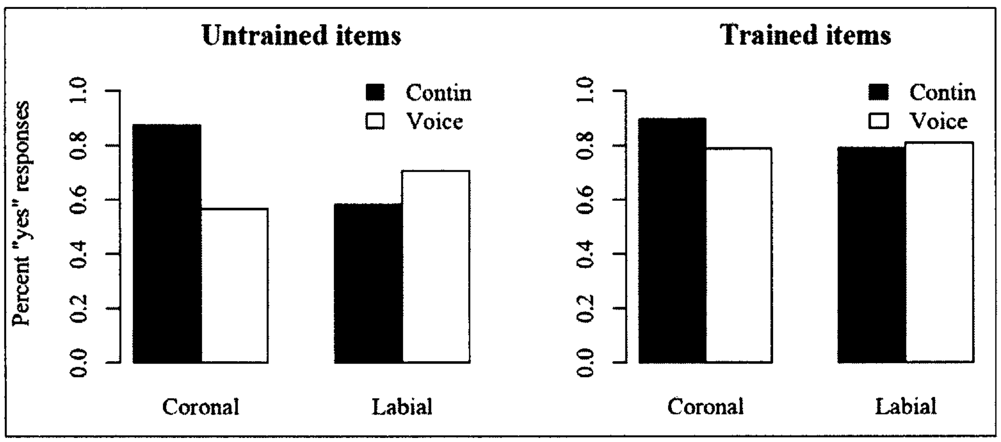
(218) The result of Experiment 2

Experiment 2	Estimate	Std. Error	z value	Pr(>|z|)	
Intercept (*cont.*)	0.5175	0.3781	1.369	<.1710	n.s.
Place (*coronal*)	1.6410	0.3091	5.310	<.0001	***

No significant coefficient for the intercept was observed; participants did not systematically prefer the continuancy alternations over the voicing alternations overall. A significantly positive effect of the place factor was found, indicating that participants preferred the continuancy alternations specifically among coronals, which mirrors the higher segmental frequency of $t \sim s$. Importantly, $p \sim f$ was not specifically preferred, even though the continuancy alternations were dominant in the language.

In the familiarity test, continuancy alternations are preferred specifically among coronals, mirroring the frequency of segmental alternations. This tendency is same as the result of the generalization test. Also as from the generalization test, no overall preference for the continuancy alternations was observed, as shown by the fact that participants preferred the voicing alternations for labials, especially strongly for untrained items. The result is illustrated in the graphs in (219).

(219) The result of the familiarity test



Trained frequencies		
	Cor.	Lab.
Contin	3	6
Voi	13	3

6.3 Patterns in learning alternations

To examine the general tendencies of learning alternations, we took both experimental results together and analyzed them using a mixed effect logistic regression model. We set up the frequent feature, voicing (Experiment 1), and continuancy (Experiment2), as the higher factor level for the intercept, so that a significant positive effect of alternation (i.e., preference for featurally more frequent alternation) can be examined. Place was entered as a factor, and we set up coronals as the positive factor, so that a positive significant effect of the place factor (i.e., preference for the alternation specifically among coronals) can be checked. The place factor was sum coded, so that the intercept is at the mean of the two levels of the places. In this combined model, experiment was entered as a factor, in order to test whether experiment 1 induced a greater feature-level preference for voicing than experiment 2 did for continuancy. The interaction of the place factor and the experiment factor was included. A random intercept was included for items, and for participants, random slopes for place by experiment as well as a random intercept were included for participants. The result is given in (220).

(220) The result of the generalization tests across the two experiments

Exps 1 and 2 combined	Estimate	Std. Error	z value	Pr(>|z|)	
Intercept (more frequent alternation)	1.1505	0.2653	4.337	<.0001	***
Place (*coronal*)	1.4888	0.2271	6.556	<.0001	***
Experiment (*exp 2*)	-0.6224	0.2667	-2.334	.0196	*
Experiment:Place	0.1570	0.2287	0.687	.4924	n.s.

As the significant positive coefficient of the intercept shows that, in general participants significantly preferred featurally more frequent alternations. A significant positive coefficient for the place factor indicates that the featurally more frequent alternations are preferred specifically for coronals, which are segmentally more frequent. In other words, learners detect the segmental frequency of alternations as well as the featural frequencies. This result suggests the interplay of the feature-level and the segment-level generalizations in learning alternations. A significant negative coefficient for the experiment factor shows that the preference for the featurally more frequent alternations was less strong in experiment 2, where the continuancy alternations were the dominant pattern. Given that the continuancy alternations are perceptually more salient relative to the voicing alternations, this result is consistent with the hypothesis that perceptually salient alternations are not generalized as readily as perceptually less salient alternations. Based on this observation, we propose a learning model which incorporates perceptual biases.

We analyzed the results of the familiarity tests by a mixed effects logistic regression model, using lme4. The basic set-up is simple: participants answered ‘yes’ or ‘no’. The interest of the test was to check whether there are significant effects of place, feature, training, experiments and their interactions. The four-way interaction of alternations (voicing vs. continuancy), places (coronal vs. labials), training type (trained vs. untrained items), and experimental effect (experiment 1 vs. experiment 2) was assumed as fixed factors. Each main factor was sum coded (1 vs. -1). In this way, the interaction of alternations and places tested for an effect of the more frequent segmental alternations: voicing among coronals and continuancy among labials. A random intercept was included for items[23]. The result is shown in (184).

[23] The full model assuming four-way slopes for types of alternations, places, training effect and experiments did not converge. We omitted two slopes for principled reasons. First no slope for experiment by participants was assumed, since each participant conducted only one experiment. Second no slopes for place or type by items was assumed, since each item has just one place, and is either trained or untrained-- that is, we did not use individual items as training for some participants and a test for others. Without the two slopes the model converged.

(221) The result of the familiarity tests across the two experiments

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept) : General bias to say 'yes'	1.30786	0.12097	10.811	<.0001 ***
Alternation21: Preference for more frequent alternations	0.25163	0.07938	3.17	<.001 **
Place1: Preference for items with coronals	0.30244	0.09748	3.103	<.001 **
type1: General bias to say 'yes' to trained items	0.56991	0.09354	6.092	<.0001 ***
Exp1: General bias to say 'yes' in Experiment 1	-0.18091	0.10728	-1.686	0.09173
Alternation21:Place1	0.68347	0.08338	8.197	<.0001 ***
Alternation21:type1	0.08414	0.0758	1.11	0.26698
Place1:type1	0.15351	0.09321	1.647	0.09958
Alternation21:Exp1	-0.02669	0.09712	-0.275	0.78346
Place1:Exp1	-0.03121	0.07982	-0.391	0.69581
type1:Exp1	0.03623	0.07496	0.483	0.62888
Alternation21:Place1:type1	0.06889	0.07439	0.926	0.35439
Alternation21:Place1:Exp1	0.14107	0.10039	1.405	0.15994
Alternation21:type1:Exp1	0.06628	0.09421	0.704	0.48172
Place1:type1:Exp1	0.06876	0.07456	0.922	0.35644
Alternation21:Place1:type1:Exp1	0.11533	0.09309	1.239	0.21539

The positive intercept indicates a strong bias toward yes answers—i.e., participants were more likely to think that the test items were in the language. There is a strong training effect, as shown in a positive main effect of type. A positive main effect of place suggests that yes responses significantly increased for items with coronals. Also, a significant increase in yes responses was found for items with the more frequent featural alternations, shown by a positive main effect of alternations. A negative coefficient for the main effect of experiment reveals that there was also a trend for more 'yes' responses in experiment 2. A strong increase in yes responses for the segmentally frequent alternations was found, as the positive main effect of the interaction of alternation and place. There was also a trend for more yes responses for trained coronal items, as shown by the main effect of the interaction of place and type. This probably means that participants were learning the trends in the data, and were better at remembering lexical items that conform to their expectations.

We were also interested in the interaction of alternation and experiment. We expected to see more of an effect of the frequent feature in Experiment 1, where the frequent feature was voicing. The coefficient is actually negative, but not significantly, suggesting that there is no main effect of the perceptual bias.

This result is different form that of the generalization test, where we found a significant effect for the perceptual bias. We attribute this result to the fact that the 'yes' rates are overall very high – i.e., it is possible that the sensitivity is too low to see subtle differences of continuancy and voicing alternations.

6.4 Incorporating biases into the learning model

The experimental results show that (a) exposure to one alternation may contribute to learning of featurally overlapping alternations and (b) the degree of this facilitation effect is sensitive to the perceptual distance of the feature that is alternating. Can we capture the attested learning patterns using current phonological grammars? If not, how can we incorporate the observed learning biases to account for the current results?

Phonological theories that make use of features can describe processes that apply to classes of segments. However, simply including features in theories does not necessarily help decide whether a process should generalize to featurally related segments. In this section, we show that the learning facilitation effect can be expressed by models using numeric weights or ranking values, but not by models using a stratified constraint hierarchy. Throughout this section, we consider a language that exhibits only two alternations, *t~d* and *p~b*, where *t~d* alternations are common and *p~b* alternations are rare. The frequencies of the two alternations in this hypothetical language are same as in the two Experiments in the preceding sections.

6.4.1 Predictions of phonological theories

Consider the predictions of learning patterns of alternation using an OT grammar formulated in terms of a stratified constraint hierarchy. We start with a widely assumed grammatical model in which featural faithfulness constraints and featural markedness constraints are assumed as in (222). This grammar does not differentiate between [t] and [p]. Exposure to *t~d* and *p~b* alternations are predicted to be equivalent in this system: learning one segmental alternation strictly implies the learning of other alternation. Regardless of its segmental frequency, the grammar as in (222) predicts an equal degree of learning of *t~d* and *p~b* alternations.

(222) A grammar in which learning one segmental alternation strictly implies the other

/at-a/	OO-Ident([±voi])	*V[–voi]V
☞a. ada	Ⓛ →	→
b. ata		W
/ap-a/		
☞a. aba	Ⓛ →	→
b. apa		W

Let us now consider the prediction of the grammar that involves segment-level constraints as well as feature-level constraints, as in (223).

(223) A set of constraints

Featural faithfulness: OO-Ident([±voi])
Segmental markedness: *VtV, *VpV

The datum [at] ~ [ada] compels the demotion of a featurally general OO-IDENT([±voi]) constraint. Recall that in our hypothetical language, *t* ~ *d* alternations are frequent, while *p* ~ *b* alternations are rare. When the faithfulness constraint is demoted below the *VtV constraint, it may still rank above the *VpV constraint as in (224), assuming that OO-IDENT(voi) is demoted only below those constraints that are strictly necessary and compels demotion below *VtV, but not *VpV. In this situation, a *p* ~ *b* alternation is not predicted at all.

(224) A grammar which does not generalize featural alternation from *t~d* to *p~b*

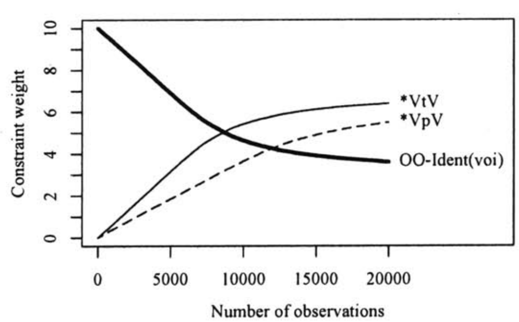
/at-a/	OO-Ident([±voi])	*VtV	*VpV
☞a. ada	Ⓛ →	→	
b. ata		W	
/ap-a/			
a. aba	Ⓛ		
☞b. apa			W

The prediction in (224) indicates that the existence of featurally general constraints, OO-Ident([±voi]) in this example, does not guarantee featural generalization from *t~d* voicing alternations to *p~b*. The predictions of a grammar with both feature-level and segment-level markedness constraints (i.e., *V[-voi]V, *VtV, *VpV) are not different than either (222) or (224), because one of the markedness constraint would be sufficient to explain the datum; for *t~d* alternations, *VtV would be sufficient.

Experimental results showed that the learning of one segmental alternation does not strictly imply the learning of the other segmental alternation, contrary to the prediction in (222). Rather, both of the experiments found that learners detect the different frequency of different segmental alternations, and generalize the patterns accordingly. Also as opposed to the prediction in (224), we found that learning of one segmental alternation facilitates the learning of other featurally overlapping alternation.

Models that use numeric weights or ranking values make different predictions from a grammar assuming a stratified constraint hierarchy. In this kind of grammar, constraints are promoted and demoted along a fixed scale (Gradual Learning Algorithm: Boersma 1997; Magri 2012; Stochastic Gradient Descent: Jäger 2007). Demoting a constraint brings its value closer to all lower-ranked constraints, not just the constraint(s) that compelled the demotion. Consider the same scenario we are assuming; in their language, *t~d* alternations are common and *p~b* alternations are rare. In models using numeric weights, even if the datum [at] ~ [ada] is taken as evidence to demote the OO-Ident ([±voi]) with respect to the *VtV constraint, the demotion of this faithfulness constraint brings it closer to the *VpV constraint, as illustrated in the schematic learning trajectory in (225).

(225) A grammar that predicts facilitating acquisition of featurally overlapping alternations

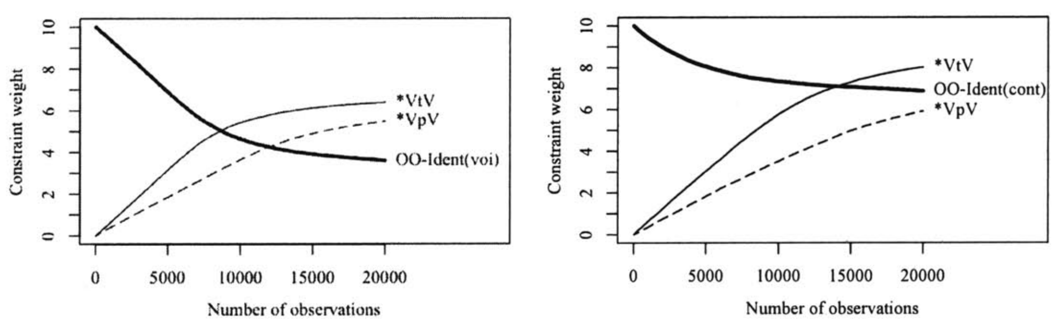


Due to the fact that the demotion of the faithfulness constraint OO-Ident ([±voi]) brings it closer not only to the *VtV constraint but also to the *VpV constraint, facilitating acquisition of *p ~ b* alternations is predicted: even though the segmental frequency of *p ~ b* alternations might be low in a given language, its acquisition would be facilitated due to the high frequency of *t ~ d* alternations, which share the same featural structure with *p ~ b* alternations. If learners adjust constraints along a fixed scale, as assumed in this model, the speed of a segmental alternation should depend not just on the frequency of a specific alternation, but also on the frequency of other, featurally overlapping alternations. If a language provides more evidence of alternations of [t] than of [p], the *VtV constraint is promoted faster than the *VpV constraint, as illustrated above. The different degrees of segment-specific markedness constraints relative to the demotion of the featural faithfulness constraints predicts different degrees of segmental alternations.

This is exactly the pattern we observed from the experiment: we were able to change the speed at which a segmental alternation is acquired by manipulating the frequency of other, featurally overlapping alternations.

Models that use numeric weights or ranking values also predict that the degree of featural facilitation should depend on how much the relevant faithfulness constraint is demoted, relative to the amount that the markedness constraints are promoted. Take our case which compares voicing and continuancy alternations as an example. Suppose a learner is perceptually biased to demote the OO-Ident([±cont]) constraint less than the OO-Ident([±voi]) constraint, thus accordingly the OO-Ident([±cont]) constraint is demoted less readily than the OO-Ident([±voi]) constraint. Continuancy alternations may not be generalized as much as voicing alternations. A schematic example in (226) shows the learning trajectories generated by Stochastic Gradient Descent (Jäger 2007). When the model found an equal amount of voicing and continuancy alternations (20000 for each alternation), it predicts that the OO-Ident([±voi]) constraint is demoted below the *VtV and the *VpV constraints, while the OO-Ident([±cont]) is demoted below the *VtV constraint but is still above the *VpV constraint.

(226) A schematic comparison between the learning of voicing and continuancy alternations



The experimental results did show a different degree of facilitation effect depending on the alternating features: more facilitation of learning voicing alternations than learning continuancy alternations.

Given that the current results can be accounted for by a grammar assuming numeric weights, we consider how to incorporate the observed learning biases into numeric-weight-based grammars.

6.4.2 Failure of an unbiased model

While the results of the generalization tests and the familiarity tests are slightly different, the general patterns of learning are similar across the two types of tests. To predict the observed results, the model needs to capture the three key properties summarized in (227).

(227) The facts to model

a. Preference for featurally more frequent alternations (voicing)
b. Greater rate of non-alternation for less frequent segments (labials)
c. Preference for segmentally more frequent alternations ($t \sim d$ over $t \sim s$, and $p \sim f$ over $p \sim b$)

To model the facts in (227), we employ three types of constraints: Faithfulness constraints that inhibit featural alternations, Markedness constraints that compel alternations and additional Markedness constraints that inhibit alternations. To inhibit voicing and continuancy alternations, we need OO-Ident([±voi]) and OO-Ident([±cont]) constraints as in (228). These constraints capture an initial preference for non-alternation, seen in the fact that participants sometimes favor non-alternation (especially for the rarer labial place), even though obstruent-final stems always showed alternations in the training data. These constraints also capture the observed facilitation effect. For instance, training on $t \sim d$ alternations facilitated the learning of $p \sim b$ alternations, by demoting OO-Ident([±voi]).

(228) Faithfulness constraints that inhibit featural alternations

a. OO-Ident([±voi]) Corresponding segments in outputs agree in voicing
b. OO-Ident([±cont]) Corresponding segments in outputs agree in continuancy

To capture the greater rate of non-alternation for less frequent segments, (227), OO-Faithfulness constraints are assumed to dominate Markedness constraints in the initial state of modeling (McCarthy 1998; Hayes 2004)—i.e., the target of faithfulness constraints was set to 15 and it was 5 for markedness constraints. In this way, OO-Faithfulness constraints relevant to less frequent segments remain closer to their initial state.

We also need Markedness constraints as in (229), banning intervocalic voiceless stops, both [t] and [p] in the current case. In order to capture different overall rates of alternation between coronals and labials, as in (227), we need place-specific Markedness constraints, as in (229).

(229) Markedness constraints that compel alternations

a. $*V\begin{bmatrix}-\text{voi}\\-\text{cont}\end{bmatrix}V$ Output forms do not have a voiceless non-continuant segment at intervocalic position

b. *VtV Output forms do not have [t] in intervocalic position

c. *VpV Output forms do not have [p] in intervocalic position

Markedness constraints may inhibit alternations as well. For the current case, when a learner finds that [t] should alternate, she may choose [d] or [s] as the surface realization, while [p] may alternate with [b] or [f]. In order to model the fact that participants prefer segmentally more frequent outputs, we included markedness constraints that can distinguish between more frequent and less frequent output segments. For this purpose, the markedness constraints in (230) were included in the simulation. For instance, if $p \sim b$ and $t \sim s$ alternations are less frequent than $p \sim f$ and $t \sim d$ alternations respectively, the *VbV constraint will be ranked above the *VfV constraint, and the *VsV will be above the *VdV. In order to make the form of constraints parallel with the markedness constraints that compel alternations in (229), we also included the general markedness constraints as in (230), which describe shared structure of outputs: one that inhibits voiced non-continuant obstruents, [b] and [d] in intervocalic position, and the other that inhibit voiceless continuant obstruents, [f] and [s] in intervocalic position.

(230) Markedness constraints that inhibit alternations

a. $*V\begin{bmatrix}+\text{voi}\\-\text{cont}\end{bmatrix}V$ Output forms do not have a voiced non-continuant segment in intervocalic position

b. $*V\begin{bmatrix}-\text{voi}\\+\text{cont}\end{bmatrix}V$ Output forms do not have a voiceless continuant segment in intervocalic position

c. *VbV Output forms do not have [b] in intervocalic position

d. *VfV Output forms do not have [f] in intervocalic position

e. *VdV Output forms do not have [d] in intervocalic position

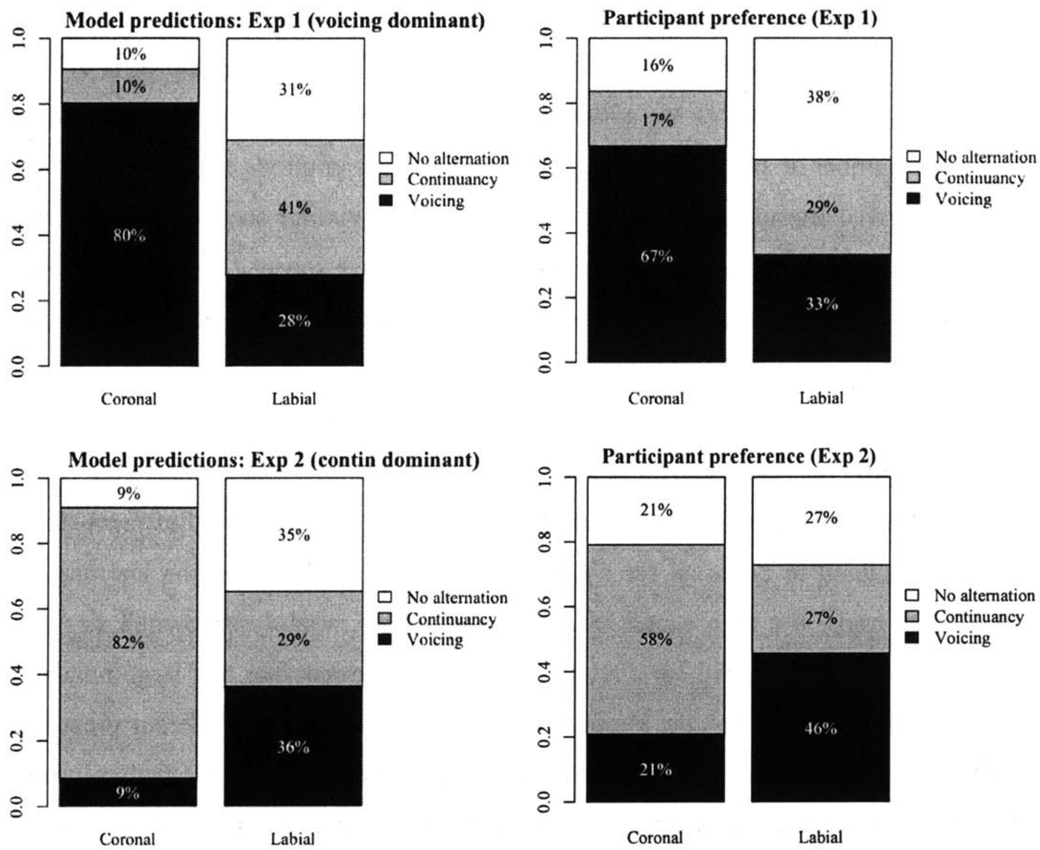
f. *VsV Output forms do not have [s] in intervocalic position

Throughout this section, we will compare the performance of the model with the results of the generalization test, not the familiarity test. An assumption behind this decision is that participants were projecting new items by extending the patterns that they generalized from the data (i.e., the generalization tests), which corresponds to the learning of new data by a model. On the other hand, the task of the familiarity test was to determine whether the items were in the language or not. This format may have made participants consider the test as a memory test, thus calling on their lexical knowledge.

We assume a maximum entropy model of weighted constraints. In this model, candidates are assigned scores, which are equal to the weighted sum of the constraint violations. When the model receives a new datum, it chooses a predicted winner for the input by sampling from the probability distribution over output candidates, given the current constraint weights. If the winner that the model sampled is different from the given output, the constraint weights are adjusted to make the observed output more probable. The adjustment rate and the number of samples can be manipulated: if one employs a smaller adjustment rate and large number of sampled learning trials, the results can be more similar across different runs of the model. In order to find constraint weights, we use stochastic gradient accent (Jäger 2007). In this model, weights of winner-preferring constraints gradually increase, and weights of loser-preferring constraints gradually decrease.

We trained the model on the artificial languages. Assuming the initial bias for OO-Faithfulness constraints, the target weights for OO-Faithfulness constraints were set higher than Markedness constraints: 15 for OO-Faithfulness constraints and 5 for Markedness constraints. The adjustment rates of constraints' weights were assumed to be equal for all constraints, 0.001, throughout the learning. The model went through 80,000 trials, the amount of which approximately mimics the overall degree of learning seen in the experimental results. We set a relatively small adjustment rate and large number of sampled learning trials, so that the result of the simulation is more similar across different runs of the model. The learning trajectory of the model revealed that the OO-Ident constraint for featurally more frequent alternations, voicing alternations, is demoted faster than OO-Ident constraints for less frequent alternations, continuancy alternations. Markedness constraints are promoted according to frequency of violations. The model's predictions after 80,000 trials are illustrated in (231), compared to participants' preferences repeated from (207) and (217).

(231) The model predictions after 80,000 trials



The model successfully predicted a greater rate of non-alternation for labials for both experiments, due to the slow promotion of the *VpV constraint. It also predicted the overall preference for the segmentally more frequent alternations across the two learning simulations of the artificial language 1 (experiment 1) and the artificial language 2 (experiment 2). The learning of the segmentally less frequent alternations among labials was facilitated by featurally overlapping alternations. In language 1, the voicing alternations were predicted more than the continuancy alternations overall. In language 2, the model preferred the continuancy alternations to voicing alternations overall.

A fatal problem of this model is that the size of the facilitation effect is too weak for the voicing alternations in language 1, and it is too strong for the continuancy alternations in language 2. In spite of the higher overall frequency of the voicing alternations in in language 1, the continuancy alternations were preferred over the voicing alternations among labials, which is opposite to participants' responses. While in Experiment 2, the continuancy alternations were not strongly preferred over the voicing alternations among labials, the model's preference for the continuancy alternations when alternations are predicted (45% = continuancy 29% / continuancy 29% + voicing 36%) was too high, relative to participants' choices for the continuancy alternations (37% = continuancy 27% / continuancy 27% + voicing 46%). In short, this model is not able to capture the proper degree of facilitation, depending on different features.

Also, the proportions predicting the non-alternation do not match well with the observed patterns. Recall that there was no single instance showing non-alternating obstruents in the training data. Comparing the model's predictions and the participants' preferences in (231), the model predicted a greater difference of no alternation between coronals and labials. This is possibly due to the fact that alternations were in general fed more for coronals than labials, so the model learned more coronal alternations. On the contrary, participants frequently preferred no alternation across two places, coronals and labials, despite no supporting evidence in the input data.

The current model is an 'unbiased' learner, in a sense that the adjustment rate of every constraint is equal. When the model's sampled winner is different from the given output, this model adjusts constraints' weights to make the observed output more probable. Due to the equal adjustment rate for every constraint, the model increased the weights of all winner-preferring constraints and decreased the weights of all loser-preferring constraints to the same degree. The current failure indicates that the different degrees of facilitation cannot be captured by an unbiased learner.

6.4.3 Incorporating biases in the learning model

Our next attempt was to train a biased learner on our artificial languages, to investigate whether the addition of biases into the learning can capture the different degree of facilitation effects for different features. The three biases in learning alternations we found from the experiments are summarized below.

(232) Biases in learning alternations

a. A bias against alternations, favoring uniform paradigms (McCarthy 1998)
b. A substantive bias against perceptually salient alternations (Steriade 2001)
c. A bias in favor of alternations that target broader classes of segments (Peperkamp et al. 2006)

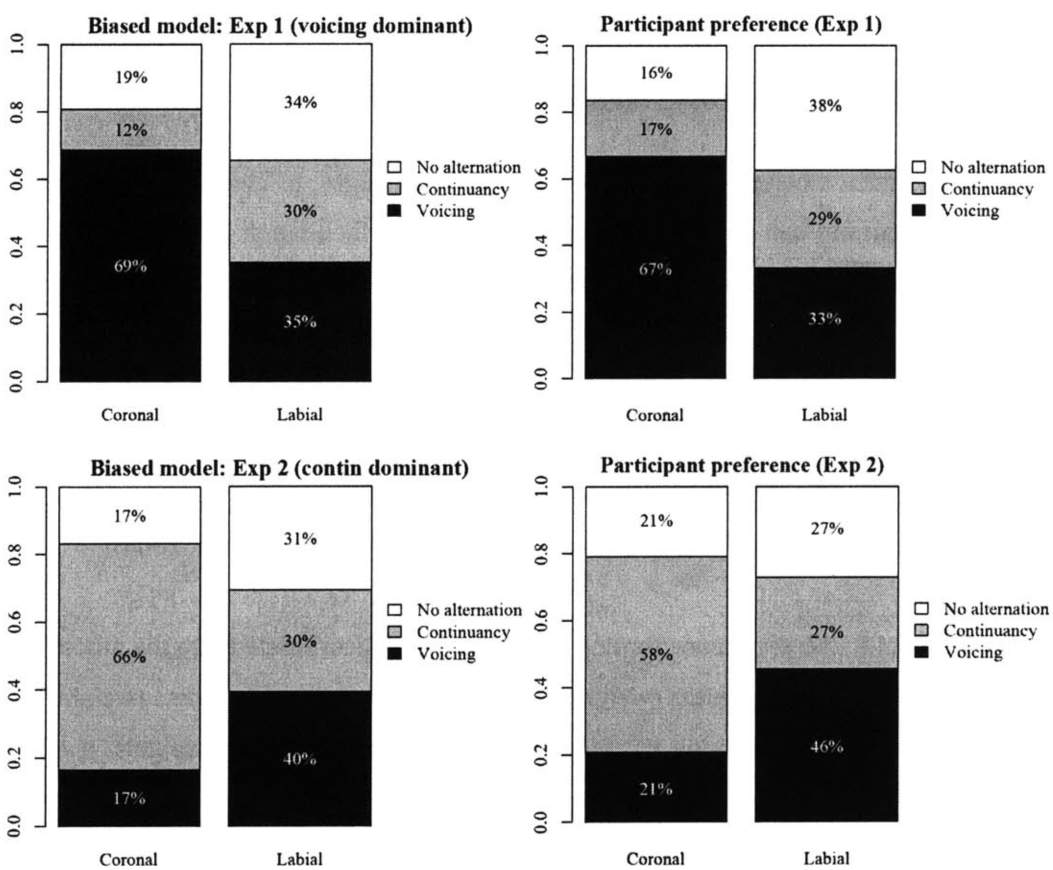
As our previous trial in 5.4.2, the preference for non-alternation was incorporated into the model with higher target weights for faithfulness constraints (weights= 15) over markedness constraints (weight = 5). We implemented biases (b) and (c) by varying σ^2. When the learning model adjusts weights, it adds a small pull back towards the initial weights. The strength of the pull can be set to vary depending on the constraints. A weak regularization means that the model is freer to find the optimal weights to fit the data, while a strong regularization means that the model is constrained to leave the weights near their initial target (see Wilson (2006), Hayes and Wilson (2008) and Hayes et al. (2009) for the idea and the application of this parameter.).

To incorporate the phonetic bias in (b), we imposed a smaller σ^2 on the OO-IDENT([±cont]) constraint, and a larger σ^2 on the OO-IDENT([±voi)]) constraint. This implementation allowed the model to adjust the weight of the OO-IDENT([±cont]) constraint less freely than the OO-IDENT([±voi]) constraint; the model is biased against adjusting the OO-IDENT([±cont]) constraint adjusted its weight 0.075 as much as general markedness constraints and the OO-Ident([±voi]) constraint was adjusted 0.5 as much as general markedness constraints.

We model the bias for simplicity in (c) by letting the model adjust general constraints more readily than specific ones; thus, *V[vcls stop]V is favored over *VtV as an explanation for coronal alternations. The regularization of the specific markedness constraints was 0.05 of that of the general markedness constraint.

The results of learning with this biased model are illustrated in (233).

(233) Model predictions



One of the main interests here is comparison of the facilitation effects of the voicing and the continuancy alternations. The biased model predicted the higher degree of facilitation for the voicing alternations in language 1: among labials, the learning of segmentally less frequent *p* ~ *d* alternations were facilitated, thus the model preferred the voicing alternations to a great degree, despite its lower segmental frequencies. The model predicted the weaker facilitation for the continuancy alternations in language 2. *p* ~ *f* alternations were not much preferred when alternating items were produced; compared to the preference rate for the continuancy alternations of an unbiased learner, the biased learner preferred the continuancy alternation less (42% =continuancy 30% /continuancy 30% + voicing 40%), and quantitatively the proportion predicted by the biased learner matches better with the participants' preference rate for the continuancy alternation in Experiment 2 (37%).

Also, the proportions of no alternation vs. alternations match better with the proportions in participants' answers: unlike the unbiased learner, the biased learner predicted 'no alternation' not specifically just among labials.

6.5 Discussion & future directions

A central finding across the two experiments is that the learning of alternations is facilitated by the constraint violations of featurally overlapping alternations. Due to the shared OO-Ident constraint violations, for example, learning *t~d* alternations facilitated the learning of *p~b* alternations, leading to an overall preference for voicing alternations. Due to the shared markedness constraint violations such as *VtV, *t~d* and *t~s* alternations lead to greater overall rate of alternation for coronals.

The current finding indicates that the interplay of segment-specific and feature-level constraints is crucial in predicting learners' generalization pattern of alternations. The higher segmental frequency of the alternations for coronals than for labials led to a greater overall rate of alternation for coronals, which was captured by the shared *VtV constraint violations. If the model only involves feature-level markedness constraints, such as *V[-voi]V, the tendency that participants preferred segmentally more frequent alternations cannot be captured. The experimental results also showed a different rates of alternation between [t] and [p], which we modeled with segment-specific markedness constraints, such as *VtV and *VpV.

It is worth noting that we do not argue for a specific way that the constraints should be formulated; the set of constraints assumed here is not the only means to capture the attested featural and segmental generalizations. Instead of utilizing featural faithfulness constraints which interact with place-specific markedness constraints, the same effect may be captured by allowing feature-based markedness constraints (e.g., *V[-voi]V) to interact with place-specific faithfulness contrasts: OO-

Ident([±voi])/[+COR], OO-Ident([±voi])/[+LAB] or a constraint such as *MAP(t ~d) (Zuraw 2007). The results here do not distinguish between these two approaches. The reason we adopt the version that we do is that it is conventional in the OT literature to state faithfulness constraints on features independently, while markedness constraints often refer to co-occurring feature values.

The current modeling results also show the importance of numeric constraint weights in the account. In our model that assumed numeric ranking scales, data about *t ~ d* alternations compels the demotion of the OO-Ident([±voi]) constraint, and the demotion is relative to all constraints, crucially including the *VpV. *t ~ d* alternations give no reason to rerank the *VpV constraint, but due to the fact that the OO-Ident([±voi]) constraint is weighted in fixed scales, the *VpV constraint becomes closer to the OO-Ident([±voi]) constraint. In the models that use a stratified constraint hierarchy, such a result cannot be captured. Suppose at the initial learning stage, the OO-Ident([±voi]) constraint and the OO-Ident([±voi]) constraint outrank the *VtV constraint and the *VpV constraint respectively. In models such as recursive constraint demotion or biased constraint demotion (Tesar and Smolensky 2000; Prince and Tesar 2004), data about *t ~ d* alternations compels the demotion of the OO-Ident([±voi]) constraint below the *VtV constraint, but the data is not informative at all about the relative ranking of the OO-Ident([±voi]) constraint, with respect to the *VpV constraint. In those models, the most conservative strategy is to maintain the initial ranking of the OO-Ident([±voi]) constraint, so that it remains above the *VpV constraint.

Another thing to note is the different results between the generalization test and the familiarity test. While participants detected featurally more frequent patterns as well as segmentally more frequent patterns in the generalization test, they accepted only segmentally more frequent patterns more in the familiarity test. Our guess is that participants may use different types of knowledge in different tasks; while learners use phonotactic knowledge to decide whether an item was in the lexicon (the familiarity test), they rely on the relative frequency of featural alternations when they are projecting new items. This difference leaves the question of why participants focus on the relation between the singular and plural more in answering some questions than others. This needs further investigation, by varying the questions to see under what conditions learners are more likely to use the featural frequencies of alternations.

It is also remarkable that fairly high rates of non-alternating obstruent-final nouns were observed in the generalization test, while the training items never showed non-alternating forms. This could be attributed to an initial bias, the initial high weight for OO-Faithfulness constraints. Alternatively, participants may have learned the preference based on the sonorant-final filler items which did not exhibit alternation. Given that forty four percent of the training items showed no stem alternation between singular and plural, it is conceivable that the identity between the singular and the plural is learned

(Albright 2009), and the learned relationship served as the evidence to prefer non-alternations even beyond what was shown for obstruent-final nouns. Another possibility is that participants simply did not pay enough attention to consonant alternations. Since the explicit task was to learn vowel quality of the suffix, participants were encouraged to pay less attention to consonant alternations.

Finally, we acknowledge that there is much left to be done to explore whether the learning of alternations is indeed facilitated by perceptual bias. Our results support a model in which the OO-Ident([±voi]) constraint is demoted more readily than the OO-Ident([±cont]). The current result is consistent with P-Map hypothesis (Steriade 2001), given that perceptually less salient alternations (i.e., the voicing alternations) are preferred to more salient ones (i.e., the continuancy alternations). A straightforward future direction is to compare more pairs which differ in their perceptual distances.

We also leave open the possibility that we may find other intrinsic biases which give rise to the different preferences for voicing and continuancy alternations. For instance, our pair exhibiting voicing alternations for coronal, *t~d*, differ only in the feature voicing. On the other hand, the pair showing continuancy alternations, *t~s*, differ in the feature stridency as well as continuancy. An ideal artificial language should have presented the pair in which only the continuancy feature alternates—e.g., *t~θ*, in order to control the complexity of featural changes with *t~d*. We did not choose *t~θ*, since [θ] is relatively underrepresented in English lexicon, compared to [d], thus participants may not prefer [θ] regardless of the learning effect. The Much more work is needed to test whether our current argument that the voicing preference is derived by perceptual bias is on the right track. The artificial language paradigm, though, appears to be a useful tool for probing such preferences.

7 Conclusion

This thesis has provided experimental and computational support for the initial OO-CORR bias in children learning phonological alternations. I showed experimental results that at the very early acquisition stage Korean-learning children incorrectly level noun paradigms as well as verb paradigms due to the OO-CORR bias; in later stages, children figure out the correct adult forms involving alternations, but they avoid producing them unless they are forced to, in the interest of satisfying the OO-CORR bias (Chapter 2). Instead, they make morphologically or lexically deviant forms which allow them to produce non-alternating forms, but which can still convey the meanings that they originally intended. It was shown that child speakers determine such alternative production forms by violating economy of production as minimally as possible –e.g., if insertion of one morpheme already enables them to create non-alternating forms, they never insert more (Chapter 3). Paradigm uniformity was preserved by child learners in a specific way. One slot of the paradigm is selected as the base form for all lexical items and other forms are inflected faithfully to the base form. I demonstrated that the base forms chosen by child learners are predicted when phonological informativeness and the availability of the surface forms are considered (Chapter 4). I explored whether the attested learning trajectories can arise by giving the learning model all of the factors I found from the experiments and from the simulations –i.e., the initial OO-CORR bias, constraints penalizing incorrect forms and repaired or deviant forms, and the privileged base form of the paradigms. The learning model using maximum entropy grammar was assumed to generalize patterns on the basis of phonological features and it traversed in an expected way (Chapter 5). Artificial language learning experiments confirmed that featural-overlap facilitates learning of alternations. The results further showed that alternation patterns are generalized based on features in a fine-grained way that reflect the perceptual bias (Chapter 6).

This thesis has been a first step to explore the OO-CORR bias. As noted in the introduction, not much work has been done about phonological learning biases among child learners, and especially in the stage of learning patterns of alternations, very little is known about the learning biases. Further empirical research is required concerning the implication of the current findings. A straightforward extension of this study is to elicit more production data from children in wider ranges of acquisition stages. It is also worth comparing the role of the OO-CORR bias in learning second language. Can we find a strong OO-CORR bias from second language learners, as this study found from the first language acquisition? If not, what are the relevant factors that make the effect of the OO-CORR bias stronger or weaker in second language acquisition than first language acquisition?

Finally, I have mentioned at several points that child learners know how to produce alternating forms as adults, but they avoid doing so. I took the fact that children were able to produce alternating forms as the evidence showing their internalized knowledge about phonological alternations; if children were not able to understand alternating forms, there is no way that they could correctly produce such forms. However, the current study do not have direct evidence about children's comprehension grammar. In order to better understand why child learners avoid producing alternating forms while they are able to do, further research on children's comprehension about phonological alternations is required.

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