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Phonological Variation in Child-Directed Speech is Modulated by Lexical Frequency

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Abstract

We investigate whether child-directed speech (CDS) contains a higher proportion of canonical pronunciations compared to adult-directed speech (ADS), focusing on Korean noun stem-final obstruent variation. In a word-teaching task, we observed that mothers use a higher rate of canonical pronunciation when addressing infants than when addressing adults. In a follow-up experiment, adults exhibited a higher rate of canonical pronunciation for high- than low-frequency words. Additional analyses conducted with only the high-frequency monosyllabic words from the two experiments found no evidence for simplified phonology in CDS when lexical frequency was controlled for. Our findings suggest that the higher rate of canonical forms in CDS, with respect to Korean morphophonological rules, is mediated by the frequency of word usage. Thus, the didactic function of CDS phonology appears to be a byproduct of mothers using familiar words with children. These results highlight the importance of considering word usage in investigating the nature of CDS.

Introduction

How does a child internalize the grammar of adult language and what role does language input play in this process? Although children's early production grammar differs from that of adults' phonology (Do, 2013; Hayes, 2004), their production patterns eventually conform to adult grammar. How does a child learn the different realizations of the same morpheme in various phonological contexts? To answer this question, we attend to the role of speech addressed to infants, or child-directed speech (CDS), in children's acquisition of phonological alternation. Specifically, we investigate patterns of phonological variation in Korean noun stem-final obstruents /t^h/, /c^h/, and /p^h/ before a vowel-initial suffix. Our analysis of production data from two experiments suggests that phonological variation is reduced in CDS, which might facilitate children's learning of morphemes and phonological rules. Crucially, however, we argue that such didactic function of CDS is a serendipitous outcome mediated by lexical frequency.

Our unconscious phonological knowledge largely consists of three components: the system for contrasts (e.g., [l]ake vs. [r]ake), the set of legal structures (e.g., [blɪk]

vs. *[bnɪk]), and patterns of alternation, i.e., varying realization of a single morpheme in different phonological contexts (e.g., can[z] ~ cap[s]) (Hayes, 2004). Previous research on the role of CDS in child's learning of phonology often focused on their acquisition of phonological CONTRASTS. The approaches were mostly phonetic, at the SUB-PHONEMIC level, acoustically investigating phenomena such as vowel formants (e.g., Bernstein Ratner, 1982, 1984a; Hartman et al., 2017; Kuhl et al., 1997; Liu et al., 2007), voice-onset time [VOT] (Baran et al., 1977; McMurray et al., 2013; Moslin, 1979; Sundberg & Lacerda, 1999), and allophonic variations of a phoneme such as /t/ (Dilley et al., 2019; Fritsche et al., 2021). The current study, however, focuses on infants' acquisition of phonological ALTERNATION, an issue which is at a SEGMENTAL or phonological level. Our research specifically centers on stem-final obstruent variation in Korean, which refers to the variation of obstruents at the end of noun stems. We investigate whether this variability is decreased in CDS, which has the potential to benefit children's acquisition of phonological grammar and vocabulary development. A reduction in variability, if found in our investigation, could indicate the reduced application of phonological rules by mothers. But it could also be a secondary effect of other factors, such as the greater use of high frequency word types in CDS compared to ADS (Jones et al., 2023).

The impact of the frequency of words used in CDS on children's learning of phonological alternations is an area of investigation that has largely been overlooked, although there is research relating lexical frequency to children's production patterns (e.g., Zamuner, 2004) and language outcome (e.g., Cychosz et al., 2021). Research on infants' acquisition of phonological categories often takes an input-output perspective, testing for evidence of phonetic enhancements (e.g., Fritsche et al., 2021; McMurray et al., 2013) or simplified phonology (e.g., Bernstein Ratner, 1984b; Buckler et al., 2018; Dilley et al., 2014) in the input that might facilitate children's acquisition of phonology. However, studies have rarely investigated the role of input frequency in infants' learning of morphophonological rules, which is the focus of our research. Our theoretical approach in phonology incorporates insights from the usage-based or frequency effects approach (Bybee, 2001; Coetzee, 2002; B. S. Phillips, 2001) in the design of the experiment and analyses.

The goal of the present study is to test the tutorial function hypothesis of CDS by analyzing perceptually distinct morphophonological alternations in Korean noun stem-final variation. As described in section 1.2, the phenomenon involves an optional morphophonemic process that is phonetically UNNATURAL as in [k'ocʰ-i] ~ [k'os-i] for the underlying /k'ocʰ-i/ 'flower-NOM'. This is in contrast to the optional coarticulatory assimilation process investigated in earlier research, such as the alternation in *ca[t] box ~ ca[p] box* (Buckler et al., 2018; Dilley et al., 2014). The non-assimilatory alternation in the final obstruents of Korean noun stems provides an excellent opportunity to test the tutorial function hypothesis of CDS, as the canonical realizations are relatively distinct in perception from their non-canonical counterparts. The distinctive nature of the Korean morpho-phonological alternation will make it easier for infants to identify the underlying representation of the morpheme when the rule is not applied, compared to phonetically natural rules like English regressive or anticipatory assimilation (e.g., cat box [kæp bɑks]). Hence, if the tutorial function hypothesis of CDS (i.e., CDS provides enhanced evidence for canonical forms) is true, we expect to find that the canonical variant of Korean noun stem-final obstruents occurs with higher frequency in Korean mothers' CDS than in ADS.

The rest of the introduction provides background information in developmental psychology and theoretical phonology relevant to our study. We first discuss the role of CDS in language acquisition, and outline the phonology of Korean noun stem-final

obstruent variation. We additionally summarize the notion of lexical frequency effects as proposed in the framework of usage-based phonology (Bybee, 2001; B. S. Phillips, 1984).

Debates on the tutorial vs affective function of child-directed speech

When adults, or even children, talk to a young child, they adapt their speech and use a special register called CDS. It is characterized as being higher and more variable in pitch (e.g., Fernald & Simon, 1984; Fernald & Kuhl, 1987; Katz et al., 1996), clearer in pronunciation (e.g., Bernstein Ratner, 1984a, 1984b; Burnham et al., 2002; Kuhl et al., 1997; Liu et al., 2007) and simpler in syntax (e.g., J. R. Phillips, 1973 – cf. Newport et al., 1977) than adult-directed speech (ADS). A characteristic of CDS that has received less attention is the simplicity of the vocabulary utilized by caregivers. Studies looking into the lexical composition of CDS report a greater number of high frequency word types in CDS than ADS (Goodman et al., 2008; Jones et al., 2023), and an increase in the proportion of rare word types with child age (Rowe, 2012). Additionally, a high proportion of basic-level words (Anglin, 1977) in young children could also be indicative of the greater use of high frequency words in CDS. The summary characteristics of CDS discussed here primarily draw from research conducted on Western populations. However, it is important to note that ethnographic studies on less investigated languages often report distinct characteristics and functions of CDS (e.g., Casillas et al., 2020, and references therein). The extent to which CDS might DIRECTLY facilitate language acquisition has been a topic of controversy. Some suggest that CDS serves as a linguistic model by providing the child listener with language input efficient for learning, which we will refer to as the TUTORIAL FUNCTION hypothesis for CDS. For example, acoustic studies of CDS suggest that there is less overlap in the acoustic cues to different phonological categories than ADS, which might facilitate infants' learning of phonological contrasts (Burnham et al., 2002; Fernald, 2000; Kuhl et al., 1997; Liu et al., 2007; Werker et al., 2007). However, others are skeptical about the didactic role of CDS, with emphasis instead being placed on its function to modulate attention and communicate emotion (Baran et al., 1977; Buckler et al., 2018; Cristia & Seidl, 2014; Singh et al., 2002), which we will refer to as the AFFECTIVE FUNCTION hypothesis for CDS.

As mentioned earlier, previous research on the function of maternal speech has mostly focused on testing hypotheses about enhanced PHONETIC cues for phonological contrasts. Our focus, however, is on the PHONOLOGICAL level. The two differing views on the role of CDS in language acquisition have led to different predictions about the degree of phonological rule application in CDS. Under the tutorial function hypothesis of the CDS, mothers might reduce the phonological variation in CDS, providing children with enhanced evidence for underlying or canonical morphemic forms. Alternatively, under the affective function hypothesis, mothers would use as many variants in CDS as in ADS, since mothers adapt their speech mainly to modulate the arousal or attention level of their infants and the enhanced evidence for canonical forms would be irrelevant to this function. The child would then have to learn lexical forms and phonological rules behind the variation simultaneously instead of being introduced to the underlying forms first, followed by relevant phonological rules.

Previous research examining the phonological and phonetic implementation of consonants in CDS reported mixed results about reduced phonological variability in CDS. In one of the earliest systematic investigations of phonological rule application in CDS, Bernstein Ratner (1984b) found that phonological processes such as dental deletion (want it → [wɒn it]), ð deletion (throw them → [θroʊ ɛm]), and the *ts/s* alternation (that's nice →

[ðæs naɪs]) applied much less frequently in CDS than ADS, though the opposite pattern was found for palatalization (did you → [dɪdʒu]). More recently, Dilley et al. (2014) found a modest tendency for CDS to have a greater rate of canonical pronunciations in assimilatory contexts (e.g., gree[n] boats ~ gree[m] boats) than ADS. The data, however, was based only on four types of word pairs embedded in a story and read in the laboratory. In addition, at the phonetic level, Fritsche et al. (2021) reported that CDS contains a significantly higher proportion of canonical pronunciation for /t/ than ADS, which they interpret as a clear and enhanced signal of the phonemic category. Their study, however, had only 8 participants covering various developmental stages. These results are compatible with the tutorial function hypothesis though each study is not without certain limitations for generalizability.

There are also reports contradicting the predictions made by the tutorial function hypothesis of CDS. Shockey and Bond (1980) conducted a study on the same phonological rules analyzed in Bernstein Ratner (1984b) and observed a higher frequency of rule application in CDS compared to ADS. The two studies, however, are hard to compare because they are based on different age groups and dialects of English. More recently, Buckler et al. (2018) tested the tutorial function hypothesis by investigating the place assimilation (e.g., gree[n] book ~ gree[m] book) phenomenon. They found that CDS contains as many assimilated, thus non-canonical, word forms in place assimilation contexts as ADS. Their findings suggest that mothers do not reduce the variability in their speech to their children, and that children learn canonical lexical forms and processes inducing phonological variation simultaneously.

It is interesting that both Dilley et al. (2014) and Buckler et al. (2018) investigated regressive assimilation phenomena but yielded conflicting results. The discrepancy could be attributed to their different research methods, such as the type of data elicited and the coding used. Putting aside the details of their methods, however, it is worth noting that English place assimilation in connected speech is generally considered a phonetically NATURAL process, motivated by the articulatory mechanism to adjust the place of assimilation across adjacent segments for more efficient articulation. In place assimilation contexts, such as the consonant cluster /nb/, the unaltered canonical realization ([nb]) is perceptually very similar to its altered non-canonical counterpart ([mb]) (Browman & Goldstein, 1989; Ohala, 1990; and others – cf. Jun, 1996). As it would be very difficult for a child (or an adult) to perceive unassimilated canonical realizations of words in place assimilation contexts, caregivers may not attempt to provide enhanced evidence for the canonical forms, as their adaptation of speech may not have a significant impact on infants' learning due to the inherent perceptual challenge.

Stem-final obstruent variation in Korean

Standard Korean has a three-way laryngeal contrast between lenis, aspirated and tense (or glottalized) obstruents, as shown below.

(1) Three-way laryngeal contrasts among Korean obstruents

	labial	coronal			velar
	stop	stop	affricate	fricative	stop
lenis	p	t	c	s	k
aspirated	p^h	t^h	c^h		k^h
tense	p'	t'	c'	s'	k'

Korean noun stems ending with any of these obstruents exhibit alternations within the inflectional paradigm, as shown in (2). In isolation forms, they may only end in (unreleased) lenis stops due to CODA NEUTRALIZATION, in which all coronal obstruents neutralize to [t] (e.g., /pat^h/ > [pat] in (2)), all labial stops neutralize to [p] and all velar stops neutralize to [k]. Before high front vocoids /i, j/, stem-final coronal stops such as /t/ and /t^h/ are realized as palato-alveolar affricates such as [c] and [c^h], respectively, due to CORONAL PALATALIZATION (e.g., /pat^h-i/ > [pac^{h}i] in (2)). Application of these rules yields a paradigm of alternations for noun-stems that end in obstruents. For instance, the final consonant of the noun stem /pat^h/ 'field' appears as [t^h] before an accusative case marker – *il* or a locative case marker -*e*, [t] in the isolation form, and [c^h] before a nominative case marker –*i* (see the surface form in (2)). In a standard rule-based analysis of these stem-final alternations, the output form before vowel-initial suffixes (except for [i]-initial ones) is posited as the underlying form (which is reflected in standard Korean orthography). The aforementioned phonological rules apply to the underlying form, resulting in the production of unreleased stops and palatalized consonants in the isolation and nominative forms, respectively. This standard analysis is illustrated by the derivation of some allomorphic forms of the stem /pat^h/ 'field' in (2). Readers can observe [t^h]~[t] and [t^h]~ [c^h] alternations by comparing the unaltered stem forms in the accusative and locative cases with the corresponding isolation and nominative forms, respectively.

(2)   Standard rule-based analysis of the alternations

	accusative	locative	isolation form	nominative
underlying form	/pat^h-il /	/pat^h-e/	/pat^h/	/pat^h-i/
coda neutralization			t	
palatalization				c^h
surface form	[pat^{h}il]	[pat^{h}e]	[pat]	[pac^{h}i]

Korean is currently undergoing an extensive historical change, which involves the emergence of innovative forms through analogy to frequently occurring forms. Prevocalic allomorphs of the noun stems, which to vary between [t^h] and [c^h] as in [pat^h-il], [pat^h-e] and [pac^h-i] in (2), are now observed to exhibit innovative variants which vary according to the place of articulation of the obstruents (Jun, 2010, and references therein). Stem-final coronal obstruents take on different forms including [s, c^h, t^h, c, t]. For example, /toc^h-e/ 'sail-LOCATIVE' exhibits the alternation among [tose] ~ [toc^{h}e] ~ [tot^{h}e] ~ [toce] ~ [tote]. [s] is, in general, the most frequent or preferred variant, while [c] and [t] are the least frequent or preferred. [c^h] and [t^h] fall in between. In contrast, non-coronal aspirated and tense stops, /p^h, k^h, k'/, alternate with their homorganic lenis counterparts, [p, k]. For example, /ip^h-e/ 'leaf-LOCATIVE' exhibits [ip^{h}e] ~ [ipe], and /puək^h-e/ 'kitchen-LOCATIVE' shows [puək^{h}e] ~ [puəke].

Accordingly, Korean noun stems followed by vowel-initial suffixes can be realized with a variety of different output forms, including the canonical forms (underlying and palatalized forms) as well as innovative variants (see (3)). Note that the phonological constraint inducing coronal palatalization is dominant in Korean in the sense that alveolar stops such as [t^h] are never allowed to occur in palatalization contexts, (e.g., before a nominative case marker /-i/). Consequently, not only the unaltered underlying forms, but also the palatalized forms may be considered as CANONICAL realizations of

Korean nouns in the sense that these are the historically correct normative forms.[1] On the other hand, those which are neither underlying nor palatalized forms can be classified as NON-CANONICAL realizations of Korean nouns. The table in (3) shows examples of canonical and non-canonical forms of some Korean noun-stem final consonants.

(3) Canonical and non-canonical realizations of Korean noun-stem final consonants (infrequent or non-existent alternations are given in parentheses; and gray indicates "not applicable.")

stem	suffix-initial vowel	canonical		non-canonical
		unaltered	palatalized	innovative variant
/ip^h/	i, i, e	p^h		p
/k'oc^h/		c^h		s, t^h (c, t)
/pat^h/	i, e	t^h		s, c^h (c, t)
	i	(t^h)	c^h	s (c, t)

It is worth noting that the final obstruents of Korean nouns, as well as their innovative variants, encompass sibilants such as [s, c^h] and aspirated stops such as [p^h, k^h, t^h]. Sibilants are perceptually prominent due to their loud and high-pitched noise (Johnson, 2006), and aspirated consonants are similarly salient. Therefore, in general, canonical and non-canonical pronunciations of Korean nouns are perceptually quite distinct from each other.

To sum up, a Korean noun such as /pat^h-e/ can be pronounced as the canonical [pat^{h}e] or innovative [pase], which are currently in free variation due to the ongoing historical change. If infants are more frequently exposed to the innovative [pase], it will be a challenge for them to learn the underlying form of the noun stem /pat^h/. If CDS serves a didactic function, therefore, we would expect a higher proportion of canonical variants such as [pat^{h}e] in CDS than ADS.

Effects of lexical frequency in phonology

For the past three decades or so, there has been increasing attention in phonology on variable phonological phenomena (Anttila, 1997; Bybee, 2001; Coetzee, 2002; Gahl, 2008). One of the best-known phenomena affected by the frequency of word-usage is the optional *t/d*-deletion in English (e.g., west [wɛst] ~ [wɛs]). The deletion of word final t/d is more likely to occur in words with higher lexical frequency (e.g., just) than words with lower usage frequency (e.g., bust) (Bybee, 2002; Patrick, 1991). An additional factor that influences the probability of the t/d-deletion is the morphological status of t/d. As pointed out in Guy (1991), deletion is more likely to apply when the target segment is part of a monomorpheme (e.g., mist), less likely when it is part of the irregular past tense morpheme (e.g., kept), and least likely when it is the regular past tense suffix (e.g., missed).

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[1]One might argue that the palatalized form of a stem should be counted as a type of non-canonical form since it is still different from its unaltered underlying form. With this change in classification, we have reanalyzed the same experimental data. The results of this reanalysis do not make any significant change with respect to the variability comparison between ADS and CDS.

Considering such an observation, the usage-based model of phonology (Bybee, 2001; B. S. Phillips, 1984, 2001) proposes two major effects of frequency: (1) high frequency words will change at a faster rate than low frequency items if the change is the result of a phonetic process (e.g., /t/ more likely to drop in the highly frequent *just* than *bust*), and (2) high frequency words are more resistant to change, if the change is a grammatical or an analogical change based on the analysis of other forms (e.g., highly frequent English irregular verbs such as *made* or *sang* resistant to regularization). These somewhat contradictory effects of frequency can be explained in that the first type of effect is on articulatorily-motivated changes where any frequently repeated motor activities become more efficient (Bybee, 2001) and that frequently used words are more predictable, so speakers can afford to be less clear (Bell et al., 2009). The latter type, on the other hand, involves analogical change where high-frequency words with stronger mental representation resist changes, whereas low-frequency words are more vulnerable to the pressure to change (Kapatsinski, 2021).

The phenomenon of our focus, Korean stem-final obstruent variation, is a morphophonological rule involving an analysis of grammatical morphemes. The usage-based approach predicts that there will be resistance to change thus a higher likelihood of canonical forms in high frequency words. Since CDS tends to use a greater number of high-frequency words than ADS (Jones et al., 2023; also see the section Additional analysis: Teasing apart register and frequency effects), the usage-based model of phonology predicts a higher proportion of canonical forms in CDS.

Overview of the current research

Our main goal is to test the tutorial function hypothesis of CDS based on Korean stem-final obstruent variation, a phonetically unnatural morphophonological rule. We aim to investigate whether CDS adapts the application of phonology to help facilitate children's discovery of the underlying forms. To address the question, we conducted two experiments employing Korean noun stems ending in /tʰ/, /cʰ/, and /pʰ/. In Experiment 1, we focus on the effect of register and compare the proportion of canonical forms in the word teaching task in CDS and ADS. The results showed a significantly higher rate of canonical pronunciation in CDS than ADS, suggesting that morphophonemic alternations in CDS provide a greater opportunity for children to discover the underlying representation of a morpheme. Due to the nature of the task, however, the target words used in CDS are easy words, whereas those used for ADS were rare items. To tease apart the confounded effect of register from lexical frequency, we conducted Experiment 2, in which we compare the pronunciation of high- and low-frequency words in ADS, and found a significantly higher rate of canonical pronunciation in high-frequency words. Additional analyses, comparing items in Experiment 1 and 2 after controlling for word frequency and length, did not find a significantly higher rate of canonical pronunciations in CDS. Putting these results together, we propose a mediation model, in which the effect of register on phonological variation found in Experiment 1 is completely mediated by the frequency effect found in Experiment 2. The collection of the data in this study was carried out in accordance with the ethical standards of the Institutional Review Board of Chosun University. (Approval No. 2-1041055-AB-N-01-2018-51).

Experiment 1: Canonicality of CDS and ADS in word teaching

The purpose of this experiment was to test the hypothesis that CDS is pronounced with less phonological variation than ADS in target contexts for a morphophonological rule. If

true, the higher rate of canonical forms in CDS could serve to provide enhanced evidence for infants to discover the underlying representation of morphemes and learn phonological alternations in their language.

Methods

Participants

Twenty-two Korean mothers of 11-month-old infants (M = 0;11.17, SD = 90 days, range = 0;8.21 to 0;17.09, 15 boys & 7 girls) participated in the study with their children. One additional participant's data were discarded due to a technical failure. Ten dyads participated in the study on-line during the COVID-19 pandemic.

Procedure

For the 12 dyads who participated in the study in person, the experiment was conducted in a quiet greeting room of the child language lab at a Chosun University. The participating mothers sat on a sofa with their child on their lap, and taught target words embedded in a custom-made picture book to their own children and to another adult (available at https://osf.io/5crwh/ along with all data in this paper). The order of the register in the word teaching task was counter-balanced. Elicitation of CDS was done at a sofa while the mother interacted with her child without any intervention by the experimenter. For all ADS teaching sessions, a male research assistant served as the adult addressee while a female research assistant kept the infant occupied with toys. The recording of mothers' production was made on a small clip-on digital recorder (SONY ICD-TX650) attached to the mothers' clothing close to the mouth and was saved in a linear PCM format (48 kHz, 16 bit).

For the 10 dyads who participated in the experiment during the pandemic, the experiment was conducted and recorded via Zoom software. Before the scheduled experiment, we sent out a headset microphone (Microsoft LifeChat LX-3000) and two picture books to each family. A female experimenter administered the experiment online with the help of a male research assistant for eliciting the ADS in the same manner as the off-line experiment. Audio was extracted from the video recording[2] with the sampling rate of 44kHz and a 16-bit depth.

Stimuli

The two picture books, custom-made for each speech register, contained three target words for each register. The target words for CDS were /sup^h/ 'woods,' /k'oc^h/ 'flower,' and /pat^h/ 'field,' all of which are common words that frequently appear in picture books for Korean children, though unlikely to be firmly stored in the lexicon of the pre-verbal infants. For ADS, words that are not likely to be known by ordinary adults were chosen as the target words to teach, (e.g., /sʌp^h/ 'brushwood,' /koc^h/ 'lynx,' /sat^h/ 'reed mat'). The decision to use different words for each register was made to maintain the ecological validity of the task. Each target word was embedded in three sentences in the beginning, middle, and final position of each sentence. The total number of occurrences for the target items was as follows: /sup^h/ 153, /k'oc^h/ 204, /pat^h/ 194 for CDS, and /sʌp^h/ 105, /koc^h/ 151, /sat^h/ 142 in ADS. Incidental occurrences of non-target items were excluded from the analysis in this section, but are included in the Additional Analyses section.

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[2]The audio in the original video recording was a lossy file (mp4) so there was likely data loss, but the quality was adequate for this experiment.

Participating mothers first read the three sentences containing each target word, then explained the target word to their children or the adult again in their own words. The story book contained nine additional nonce word targets used for another study. The recording session containing both the reading and the spontaneous speech for each register lasted about 10 minutes, respectively.

Coding

The recordings were transcribed in the CHAT format of CHILDES (MacWhinney, 2000) by two research assistants based on the criteria in Ko et al. (2020). Utterances containing the target words were extracted using the `kwal` command of the CHILDES' CLAN program and sent to Praat (Boersma & Weenink, 2020) for coding phonological alternations. Two research assistants, who were knowledgeable about the phonological phenomenon but naïve about the purpose of this research, coded the data based on aural inspection of the target words. Since the phenomenon was categorical, spectral inspection of sub-segmental properties was not necessary for making judgments. The research assistants identified the orthographic form of the target word, which is also the underlying form in Korean, and transcribed the actual pronunciation. They then annotated the underlying and surface representation of the target consonant in the word. Although the phenomenon was robust and did not involve any particular difficulty in identifying the alternation, we analyzed the agreement between the two coders using a set of samples from Experiment 2 and found high agreement (Cohen's κ= 0.97). Details of the agreement statistics are reported in the Experiment 2 section.

Results

The mean proportion of canonical form was higher in CDS (unaltered = 0.72, unaltered + palatalized = 0.79) than in ADS (unaltered = 0.38, unaltered + palatalized = 0.41). A breakdown of these numbers for each coda segment is summarized in Table 1, and shown for each coda segment and participant in Figure 1.

As shown, the rates of canonical forms are higher in CDS (M = 0.79 or 436/551) than in ADS (M = 0.41 or 164/398), regardless of the type of stem-final coda obstruents. To statistically test this difference, we constructed a mixed effects logistic regression model as will be described below. The dataset consists of 949 productions from the six items (the number of occurrences is shown in parentheses): /sup^h/ (153), /k'oc^h/ (204), /pat^h/ (194), /sʌp^h/ (105), /koc^h/ (151) and /sat^h/ (142). A mixed effect logistic regression model was fitted to the data using the glmer function from the lmerTest package (Kuznetsova et al.,

Table 1. Rate of Canonical Form Realization in Different Registers

stem-final C	canonical form type	register	
		ADS	CDS
/p^h/	unaltered	0.47 (49/105)	0.95 (146/153)
/c^h/		0.42 (64/151)	0.70 (143/204)
/t^h/		0.28 (40/142)	0.57 (110/194)
	unaltered + palatalized	0.36 (51/142)	0.76 (147/194)

Note. Numbers in parentheses = number of canonical realizations / total number of realizations. ADS: adult-directed speech; CDS: child-directed speech.
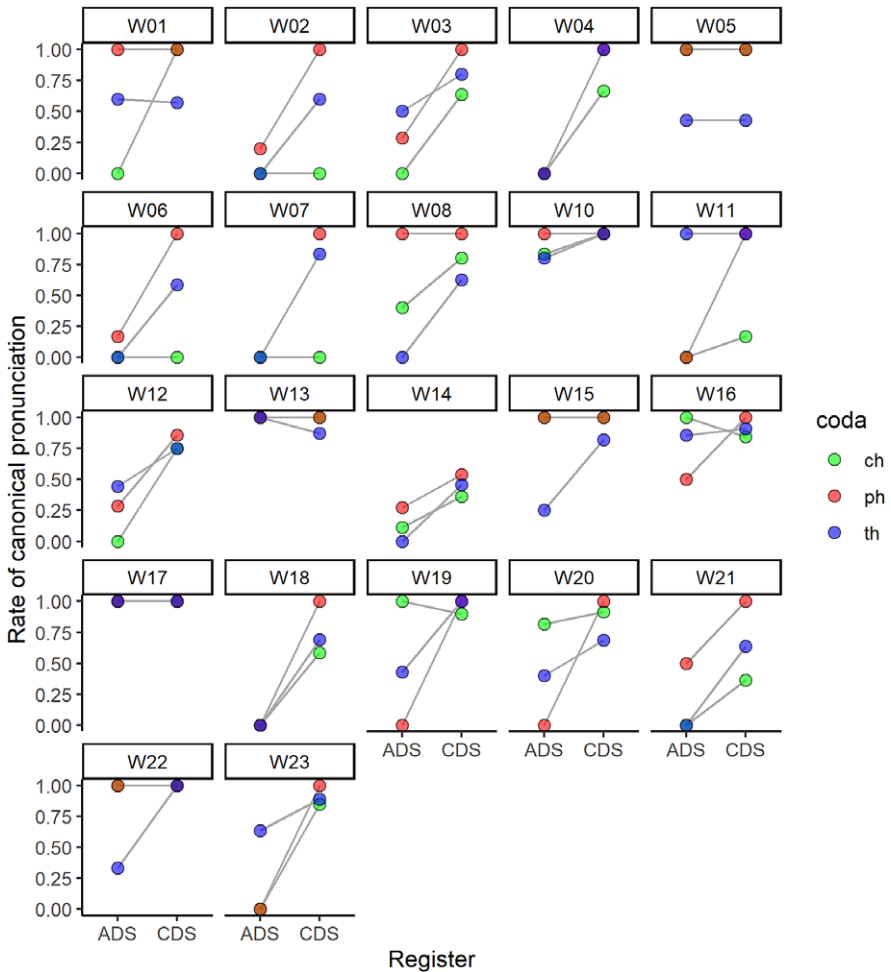
Figure 1. Rate of canonical pronunciation (unaltered + palatalized) for noun-stem final codas in ADS and CDS averaged for each participant and coda consonant.

2017) in R (R Core Team, 2022). The binary dependent variable was either "canonical" (underlying or palatalized) or "not" (reference level). In addition to REGISTER (ADS (reference), CDS), our main variable of interest, we added to the model CODA (cʰ (reference), pʰ, tʰ), (ɨ (reference), e, i), and STYLE (reading (reference), spontaneous). All fixed effect factors were dummy coded, and the random effect structure of the model included random intercepts for both subjects and items, and by-subject random slopes for REGISTER and CODA.[3] The resulting fixed effects are shown in Table 2.

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[3]Following Barr et al. (2013), we started by fitting a model with a maximal random effect structure justified by the data, and simplified the model by dropping random effect terms until the warning about overfitting disappeared.

Table 2. Mixed Effects Logistic Regression Testing the Proportion of Codas Being Realized in Their Canonical Output Form in CDS and ADS of Experiment 1

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	−1.7062	1.4501	−1.1766	0.2394
register(CDS)	3.3868	0.9449	3.5844	<0.001 ***
coda(p^h)	2.7351	1.4074	1.9433	0.052.
coda(t^h)	−0.1947	1.2387	−0.1572	0.8751
vowel(e)	1.4275	0.3375	4.2295	<0.001 ***
vowel(i)	1.0353	0.2601	3.981	<0.001 ***
style(spontaneous)	−0.5634	0.2442	−2.3069	0.0211 *

Note. CDS: child-directed speech; ADS: adult-directed speech.
*p < .05, **p < .01, *** p < .001.

The coefficient of REGISTER suggests that the rate of canonical form realization is higher in CDS than in ADS, supporting the tutorial function hypothesis of CDS. In addition, there were main effects of VOWEL (whereby the rate of canonical form realization is higher before /e/ and /i/ than before /ɨ/) and STYLE (whereby the rate of canonical form realization is lower in spontaneous speech than in read speech). We additionally constructed a model that incorporated the experiment mode (online vs offline) as a fixed factor to investigate potential impacts of different data collection modes on the mothers' pronunciation. However, we found no significant effect of the experiment mode (p = 0.99). Detailed results of this model can be accessed in the supplementary material available on the OSF repository.

Discussion

The results of our first experiment showed that mothers provide information on the underlying representation of coda consonants significantly more often in CDS. Our findings, therefore, seem to support the tutorial function hypothesis of CDS.

However, the study design may have potential confounds due to the focus on maintaining the ecological validity of the task. The mothers' teaching targets consisted of common, high-frequency words, while the ones used to teach adults were rare, low-frequency words, as demonstrated by the token frequency of these words in the Sejong Corpus, one of the most representative corpora of Korean, as shown in (4).

(4)   The usage frequency in the Sejong Corpus (B.-M. Kang & Kim, 2009) of the target noun stems used in the current word-teaching task

CDS		ADS	
/k'oc^h/	4,126	/sat^h/	17
/sup^h/	1,783	/sʌp^h/	9
/pat^h/	218	/koc^h/	0

It is, therefore, possible that the register effect is confounded with the frequency of the word-usage. To investigate the effect of lexical frequency on the canonicality of

pronunciation, we conducted Experiment 2 where we compared high- and low-frequency words elicited from participants without involving infants.

Experiment 2: Canonicality in low- and high-frequency words in ADS

The goal of this experiment was to investigate the effects of frequency on the realization of the noun-stem final consonants. Specifically, we test the hypothesis that high frequency words are resistant to change, and, thus, demonstrate a greater proportion of canonical over innovative forms in production compared to low frequency words. The participants for this study were adults only, with whom we conducted a series of experiments designed to elucidate the effect of lexical frequency on phonological variation. In this paper, the notion of frequency refers to stem token frequency, including the forms with all types of suffixation.

Methods
Participants
Twelve college students of Chosun University, recruited by an advertisement posted on the university's electronic classifieds, participated in the experiment in pairs. After excluding data from one student who already knew the purpose of the study, data from the remaining eleven participants were analyzed. We recruited them in pairs in order to elicit target words in a casual speech register for tasks involving conversation between partners. Pairing random participants would have yielded a more formal register, which would not be ideal to compare with the almost-always casual CDS. This control of formality helped avoid the potential confound of social distance (see Labov, 1972 for an explanation about style shifting) and allowed for the focus to be entirely on the frequency effect. The students were paid for their participation.

Procedure
The experiment was conducted in a sound-attenuated booth at Chosun University. The experiment consisted of three tasks. First, each participant READ a passage containing target words projected on a computer screen. Second, the participants carried out the MAP TASK (Anderson et al., 1991) designed for eliciting spontaneous speech in a pair. In the map task, the Instruction Giver gives directions to the Instruction Follower. Each has a map in front of them with slightly different information. The Instruction Follower is tasked with finding the destination on their own map to facilitate a back-and-forth verbal interaction. We embedded the target words as the landmarks in map, which ensured the production of these words, while the participants communicated about the route (e.g., Do you see the flag that says $k'oc^h$ next to the house?), being unaware of the discrepancy between their maps. We then switched their roles to elicit as many tokens as possible from every participant. Finally, they participated in a SEMANTIC MINIMAL PAIR TASK, whereby the participants are asked to explain the meaning of a target word or phrase in comparison to its semantic counterpart (e.g., /sot^h-kwa huraipɛn-ɨn ət'ək^{h}ɛ tarɨnkajo/? 'How is a pot / sot^h/ different from a pan?'). The pairs took turns in answering the questions designed to elicit production of the target words (e.g., /sot^h-ɨn kuk k'irinɨntɛ s'ɨko…/ 'Pot /sot^h/ is used for cooking soup, and…').

Stimuli
We selected six high-frequency monosyllable word items ending in our target consonants, with Google hits greater than 10,000K based on the stem form, and six low-

frequency monosyllable words with Google hits lower than 1,000K (as of October 4, 2019). In the reading task, participants read these 12 monosyllabic words embedded in a made-up passage. Additionally, 12 disyllabic words were derived by adding another monosyllabic morpheme before the 12 monosyllabic target words to test any effect of syllabic position on the realization of the target consonant (Beckman, 1998). The list of these 24 words is in (5). Out of the 12 monosyllabic words, we chose four words ending in either /cʰ/ or /tʰ/ in each of the high- and low-frequency categories and prepared them to be used for the semantic minimal pair task and the map task by creating contexts to embed them. We focused on /tʰ/ and /cʰ/ for the spontaneous speech in order to elicit the two coronal consonants, which have a greater number of variants and lower canonicality rate than /pʰ/ (Tables 1–2). Thus, each participant produced 24 types of words in the reading task, 12 high and 12 low, and eight types of target words, four low and four high frequency items, in the two spontaneous tasks.

(5) Stimuli for the lexical frequency experiment in ADS[4]

	High frequency words	Low frequency words
Reading	/k'ocʰ/ 'flower,' /pʰul-k'ocʰ/ 'grass and flower,' /picʰ/ 'light,' /kim-picʰ/ 'golden glow,' /sotʰ/ 'pot,' /pap-sotʰ/ 'rice cooker,' /patʰ/ 'field,' /tʰəs-patʰ/ 'veggie garden,' /ipʰ/ 'leaf,' /pʰul-ipʰ/ 'grass leaf,' /cipʰ/ 'straw,'/sal-kacʰ/ 'skin'	/ocʰ/ 'lacquer,' /seŋ-ocʰ/ 'raw lacquer,' /satʰ/ 'mat,' /ko-satʰ/ 'narrow alley,' /totʰ/ 'pig,' /am-totʰ/ 'female pig,' /sʌpʰ/ 'collar/brushwood,' /hotʰ-sʌpʰ/ 'single-layer collar,' /sapʰ/ 'shove,' /pu-sapʰ/ 'shovel for fire,' /mil-cipʰ/ 'wheat-straw,'/kacʰ/ 'skin'
Semantic minimal pair	/k'ocʰ/ 'flower,' /picʰ/ 'light,' /sotʰ/ 'pot,' /patʰ/ 'field'	/kacʰ/ 'skin,' /ocʰ/ 'lacquer,' /satʰ/ 'mat,' /totʰ/ 'pig'
Map task	/k'ocʰ/ 'flower,' /picʰ/ 'light,' /sotʰ/ 'pot,' /patʰ/ 'field'	/kacʰ/ 'skin,' /ocʰ/ 'lacquer,' /satʰ/ 'mat,' /totʰ/ 'pig'

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[4]We looked up the frequency of these words in Sejong Corpus (B.-M. Kang & Kim, 2009). Among the high-frequency words, the least frequent one has a frequency of 70 (/pʰul-k'ocʰ/ 'grass flower'). In contrast, among the low-frequency words, the most frequent one has a frequency of 35 (/kosatʰ/ 'a narrow alley'). In the disyllable stimuli, /mil-cipʰ/ 'wheat-straw' (17 occurrences) and /sal-kacʰ/ 'skin' (189 occurrences) showed a reverse frequency pattern from their monosyllable base /cipʰ/ and /kacʰ/.

Coding

A research assistant with knowledge of the phonological phenomenon aurally located the target words in Praat, and followed the same scheme used in coding the target words in Experiment 1.

Reliability of coding

A second research assistant coded a total of 123 instances of the target consonants (about 19% of the entire data) to test the reliability of the coding, including four participants from the map task, two from the semantic minimal pair task, and two from the reading task. The perceived realization of three target coda consonants (/cʰ/: [cʰ, s], /tʰ/: [tʰ, s, cʰ], and /pʰ/: [pʰ, p]) between the two coders was compared in a 7 x 7 contingency table. Cohen's kappa indicated a near perfect agreement between the two coders, $\kappa = 0.97$ (95 CI, 0.094 to 1.003), $p < 0.001$.

Results

The mean proportion of canonical forms was higher in high frequency words (unaltered = 0.65, unaltered + palatalized = 0.69) than in low frequency words (unaltered = 0.48, unaltered + palatalized = 0.54). The breakdown of the rates for each of the target consonants is summarized in Table 3, and shown for each coda segment and participant in Figure 2.

We can observe that high frequency words show a higher rate of canonical form realization than low frequency words, across all stem-final coda consonants.[5]

To statistically test the significance of the asymmetry observed in Table 3, we fitted a mixed effect logistic regression model to the data from the three tasks (602 data points from 24 items) with CANONICALITY as the dependent variable (canonical form = 1, variant = 0). Note that, in addition to the underlying forms, we counted the palatalized form of /tʰ/ as canonical. Besides FREQUENCY (low (reference), high), the variable of our main interest, we added to the model, SYLLABLE COUNT (1 (reference), 2), CODA (cʰ (reference), pʰ, tʰ), VOWEL (ɨ (reference), e, i), and TASK (reading (reference), map, min(imal) pair). Following the procedure adopted in the analysis presented in Experiment 1, all the fixed effect factors were dummy coded, and the random effect structure of the model included random intercepts for both subjects and items, and by-subject random slopes for FREQUENCY and SYLLABLE COUNT. The resulting fixed effects are shown in Table 4.

Table 3. Rate of Canonical Form Realization in Low and High Frequency Words in Experiment 2

stem-final C	canonical form type	usage frequency	
		low	high
/pʰ/	unaltered	0.73 (32/44)	0.95 (42/44)
/cʰ/		0.64 (76/119)	0.82 (122/148)
/tʰ/		0.24 (29/123)	0.33 (41/124)
	unaltered + palatalized	0.37 (45/123)	0.43 (53/124)

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[5]The higher rate for /pʰ/ could partly reflect a reading effect since it was elicited only in reading.
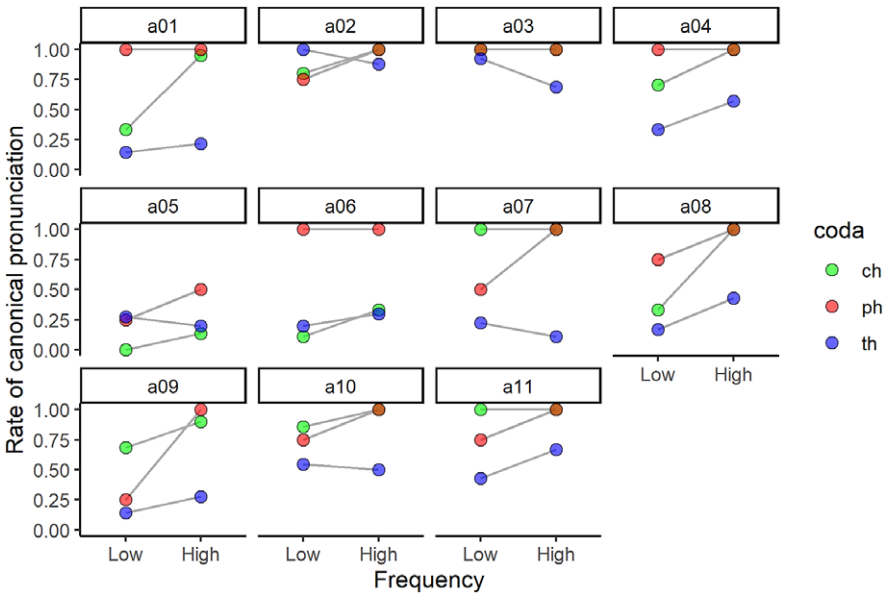
Figure 2. Rate of canonical pronunciation (unaltered + palatalized) for noun-stem final codas in low and high frequency words averaged for each participant and coda consonant.

Table 4. Experiment 2: Mixed Effects Logistic Regression Testing the Proportion of Codas Being Realized in Their Canonical Output Form on Surface

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.4114	0.7714	3.1259	0.0018 **
frequency(high)	1.2051	0.4786	2.5181	0.0118 *
syllable count(2)	−1.764	0.5887	−2.9966	0.0027 **
coda(p^h)	0.1462	0.6039	0.2422	0.8087
coda(t^h)	−2.3631	0.475	−4.975	<0.001 ***
vowel(e)	0.6797	0.4975	1.3661	0.1719
vowel(i)	0.7927	0.3164	2.5056	0.0122 *
task(map)	−2.466	0.4999	−4.9329	<0.001 ***
task(min pair)	−1.6407	0.5393	−3.0421	0.0023 **

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

Our main finding, as shown by the coefficient of FREQUENCY in Table 4, is that high-frequency words are more likely to be pronounced with the canonical form. We also observe main effects of SYLLABLE COUNT (with disyllabic words having a lower rate of canonical pronunciation than monosyllabic items), CODA (with /t^h/-final stems having a lower rate of canonicality than /c^h/-final stems), VOWEL (with a higher rate of canonicality before /i/ than before /ɨ/) and TASK (with a lower rate of canonicality in the map and minimal pair tasks than in the reading task).

Discussion

Our second experiment investigated the effects of lexical frequency on the realization of noun-stem final consonants in ADS. The results revealed that lexical frequency does have an effect, with a higher rate of canonical form realization observed in high- than low-frequency words. This finding is consistent with our speculation that the effects of register and word frequency were confounded in Experiment 1, where we found a higher rate of canonical forms in CDS than ADS. This earlier finding could, at least in part, be explained by the higher frequency of word usage in CDS. If true, we can predict that the pronunciation in CDS will no longer be more canonical than ADS if the frequency of words is controlled for. In the Additional Analysis section, we test this hypothesis by analyzing a set of high frequency monosyllable words in CDS and ADS compiled from the data obtained in the two experiments.

Additional analysis: Teasing apart register and frequency effects

We conducted further analyses to disentangle the effects of register and frequency. In the first analysis, we focused on monosyllabic high frequency words to control for the effects of frequency and word length. In the second analysis, we investigated the variability of two specific word items used both in CDS and ADS. Finally, we statistically test the hypothesis that CDS adopts more high frequency words than ADS. Our results will show that there is no evidence to support the notion that CDS has a simpler phonology independent of word-usage frequency.

Monosyllabic high frequency words in CDS and ADS

The production data in CDS of Experiment 1 consisted of 551 target and eight non-target monosyllabic high frequency words (Table 5). To compare the production of words in the two registers with frequency controlled for, we combined these words with the same type of words from Experiment 2 in ADS. Note that, as shown in the results of Experiment 2, both

Table 5. Number of Occurrences of Items in CDS (Experiment 1) and ADS (Experiment 2)

item		ADS	CDS
ip^h	'leaf'	15	1
nip^h	'swamp'	11	0
cip^h	'straw'	11	0
sup^h	'woods'	2	153
jʌp^h	'side'	0	1
k'oc^h	'flow'	62	204
pic^h	'light'	56	5
pat^h	'field'	62	194
sot^h	'pot'	41	0
mit^h	'bottom'	8	1

Note. CDS: child-directed speech; ADS: adult-directed speech.

Table 6. Monosyllabic High Frequency Words: Rate of Canonical Form Realization in Different Registers

stem-final C	canonical form type	register	
		ADS	CDS
/pʰ/	unaltered	0.92 (36/39)	0.96 (148/155)
/cʰ/		0.82 (97/118)	0.70 (147/209)
/tʰ/		0.35 (39/111)	0.57 (111/195)
	unaltered + palatalized	0.46 (51/111)	0.76 (148/195)

Note. Numbers in parentheses = raw frequency of canonical forms / total number of relevant forms. ADS: adult-directed speech; CDS: child-directed speech.

frequency and syllable count have significant effects on the rate of canonical form realization. We, therefore, only include monosyllabic high frequency words in the analysis, omitting disyllabic words. The total number of monosyllabic high frequency words included in the analysis for CDS were 559 (from Experiment 1), and 268 for ADS (from Experiment 2). The list of word items analyzed and their occurrences in each register are presented in Table 5.

The rate of the monosyllabic words produced with the canonical forms in CDS (unaltered = 0.73, unaltered + palatalized = 0.79) did not differ substantially from that in ADS (unaltered = 0.64, unaltered + palatalized = 0.69). A summary of the breakdown of these numbers for each coda segment in each register is presented in Table 6.

A higher rate of canonical form realization in CDS can be observed primarily in /tʰ/-final stems while the opposite tendency is found in /cʰ/-final stems. For /pʰ/-final stems, there is only a small difference of 4% between ADS and CDS. Thus, it is difficult to identify a clear pattern, although the mean rate of canonical form realization is higher in CDS than in ADS.

The production data of monosyllabic high frequency words (827 data points from the 10 word items) were analyzed using a mixed effect logistic regression model with CANONICALITY, including the underlying and palatalized forms, as the dependent variable (canonical form = 1, variant = 0). In addition to our main factor of interest, REGISTER (ADS (reference), CDS), we included CODA (cʰ (reference), pʰ, tʰ/), VOWEL (i (reference), e, i), and STYLE (reading (reference), spontaneous (map/semantic minimal pair tasks)) in the model. All the fixed effect factors were dummy-coded, and the random effect structure of the model included random intercepts for both subjects and items and by-subject random slopes for VOWEL. The resulting fixed effects are shown in Table 7.

The results indicate that the main effect of REGISTER is not significant, supporting our argument that the effect of REGISTER observed in Experiment 1 is largely due to the high frequency words used in CDS. To corroborate this conclusion, the next section provides item-specific comparisons.

Common lexical items across CDS and ADS

We limited our analysis to high-frequency monosyllabic words in CDS (Experiment 1) and ADS (Experiment 2) in the preceding section. However, two of these words, /k'ocʰ/ 'flower' and /patʰ/ 'field,' have a significant number of occurrences in both experiments, as shown in (6). These words were taught to children in Experiment 1 but not to adults, and thus there were no ADS tokens of these words in (6) in Experiment 1, except for a few incidental productions, as shown in Table 5.

Table 7. Monosyllabic High-Frequency Words: Mixed Effects Logistic Regression Testing the Proportion of Codas Being Realized in Their Canonical Forms

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.3732	0.726	1.8915	0.0586.
register(CDS)	−0.1737	0.5217	−0.3329	0.7392
coda(p^h)	2.3322	0.8368	2.7871	0.0053 **
coda(t^h)	−1.1102	0.7311	−1.5186	0.1289
vowel(e)	1.5014	0.3346	4.4866	<0.001 ***
vowel(i)	1.8323	0.4808	3.8107	<0.001 ***
style(spontaneous)	−0.7817	0.2505	−3.1208	0.0018 **

Note. CDS: child-directed speech.
*$p < .05$, **$p < .01$, *** $p < .001$.

(6)   Number of occurrences of two test words used across CDS and ADS

	CDS (Experiment 1)	ADS (Experiment 2)
k'oc^h	204	59
pat^h	194	61

Previous large-scale survey studies on Korean stem-final variation – namely, H.-Y. Choi (2004) and E. J. Kang et al. (2004) – have examined variation involving the two words, /k'oc^h/ 'flower' and /pat^h/ 'field'. H.-Y. Choi (2004) consulted a total of 1,174 Seoul Korean adult speakers about their actual pronunciations, while E. J. Kang et al. (2004) consulted 156 Seoul Korean adult speakers about their preferred pronunciations. In Table 8, we compare the rates of canonical form realization of the two words /k'oc^h/ and /pat^h/ in different vowel contexts, as reported in the three studies, including our current study.[6]

Table 8a indicates that for /k'oc^h/, the average rates of canonical form realization in CDS (Experiment 1) are lower across different vowel contexts compared to those in ADS in Experiment 2, but higher than those reported in H.-Y. Choi (2004) for ADS. Therefore, it is unlikely that the pronunciation of /k'oc^h/ is less variable in CDS than in ADS since the rate of canonical form realization of /k'oc^h/ in CDS falls within the range of rate variation in ADS. On the other hand, Table 8b for /pat^h/ shows the opposite trend. The canonical form realization rates in CDS across different vowel contexts are higher than in ADS of the current study, but lower than those reported in previous ADS studies, except for one case in which the rate before –e is slightly higher in CDS (0.94) than in ADS reported by Choi (0.88). It seems that the observed rates of canonical form realization of /pat^h/ in CDS also fall within the range of rate variation in ADS. The analysis of the two words used frequently in both CDS and ADS of the current study suggest that the rate of canonical form realization in CDS is not meaningfully different from ADS.

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[6]E. J. Kang et al. (2004) report separate results for different age groups, and those shown in the table are from the participants in their 20s and 30s, who are closest in age to the adult participants in the present experiments.

Table 8. Rate of Canonical Form Realization in Different Vowel Contexts

(a) /k'och/				
		_i	_ɨ	_e
CDS	this study: Exp 1	0.81	0.69	0.52
ADS	this study: Exp 2	0.83	0.77	n.a.
	H.-Y. Choi (2004)	0.73	0.68	0.47
(b) /path/				
		_i	_ɨ	_e
CDS	this study: Exp 1	0.71	0.37	0.94
ADS	this study: Exp 2	0.58	0.13	0.92
	H.-Y. Choi (2004)	0.77	0.77	0.88
	E. J. Kang et al. (2004)	n.a.	0.5	1

Note. n.a = not available. CDS: child-directed speech; ADS: adult-directed speech.

Lexical frequency in CDS and ADS

We additionally investigated the intuition that mothers use a higher proportion of easy, common words to their children than to adults. To test the null hypothesis that the frequency of word items in CDS and ADS does not differ, we compiled a list of word types used in the CDS of Ko corpus, consisting of transcripts of 35 mother-child dyads' interactions (Ko et al., 2020), and the ADS in the Call-Friend Korean corpus, which includes transcriptions of 100 telephone conversations between friends (Ko et al., 2003). We subsequently cross-referenced the word count of each word type against the colloquial section of Everyone's Corpus (word count = 3,480,224; National Institute of Korean Language, 2021). Words not found in Everyone's Corpus were assigned a count of 0. We converted the frequency of each word type in the corpus into log 10 frequencies using "+1 smoothing", which involved adding 1 to the frequency count of each word type to avoid taking the logarithm of 0, and to provide a small degree of smoothing to the data. We then conducted a t-test to compare the word frequency of the items in the two registers. The results ($t[12594] = -20.63$, $p < 0.001$) show that the log mean frequency of words used in CDS (M = 3.04, SD = 1.31) was significantly higher than that of words used in ADS (M = 2.72, SD = 1.00), confirming that words used in CDS are generally more frequent.

General discussion

To address the question of how infants learn phonology and the potential role of input in this process, previous research has largely examined whether caregivers' speech offers enhanced phonetic cues for phonological contrasts. The significance of conducting such investigations in relation to infants' phonological learning lies in their ability to establish the PHONEME inventory of their language. In this study, however, our main focus was on how infants may discover the underlying representation of a MORPHEME despite its diverse realizations in various phonological contexts. Accordingly, we investigated

patterns of phonological alternation in the input, specifically focusing on Korean noun stem-final consonants.

In Experiment 1, our findings revealed that CDS exhibits a significantly higher rate of canonical pronunciation compared to ADS. In Experiment 2, we identified a significantly higher rate of canonical pronunciations in high-frequency lexical items compared to low-frequency items among adult participants. When we conducted additional analyses, comparing CDS items in Experiment 1 and the ADS items in Experiment 2 while controlling for lexical frequency and syllable count, we found no difference in the rate of canonical pronunciations in CDS and ADS. These findings suggest that the phonological alternations present in everyday input provide valuable opportunities for children to discover the underlying representation of morphemes, eventually internalizing the phonological grammar of adult language. It is crucial, however, to note that the didactic function of CDS phonology is mainly attributable to the high frequency of the lexical items used in CDS (e.g., Goodman et al., 2008; Jones et al., 2023; Additional Analysis), and this should not be taken as a direct reflection of the caregiver input's tutorial role.

Our findings suggest a mediation model (Figure 3) that provides an explanation for the relationship between register, lexical frequency, and phonological variation. Firstly, as reported in our Additional Analysis section, caregivers use a higher rate of high frequency lexical items when communicating with their children (step (a) in Figure 3). Secondly, as demonstrated in Experiment 2, high-frequency words exhibit significantly less phonological variation than low-frequency words (step (b) in Figure 3). Thirdly, Experiment 1 shows that CDS displays significantly less phonological variation than ADS (step (c) in Figure 3). Finally, in the first two sub-sections of Additional Analysis, we show that controlling for lexical frequency eliminates the significance of the effect of register on phonological variation (step (c') in Figure 3), although we do not have a proper model with both the register and frequency. Overall, our results suggest that the relationship between speech register and phonological variation is fully mediated by lexical frequency.

Our study appears to be one of the first to suggest that the serendipitous advantages of CDS in infants' learning of phonological alternations are a by-product of using high-
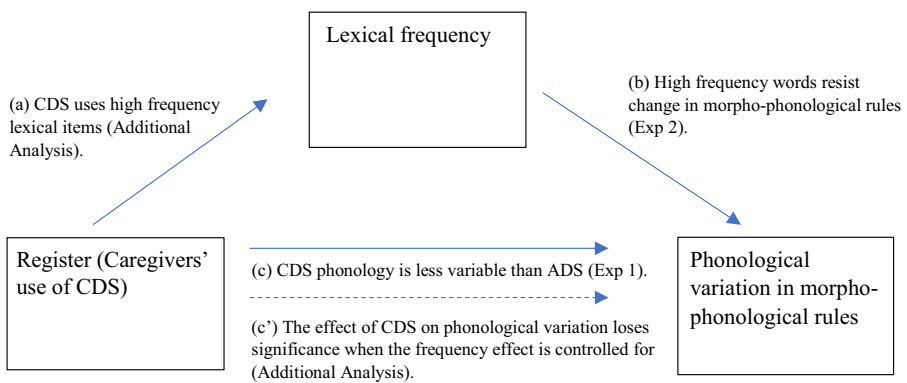

Figure 3. Mediation model. (a) represents the effect of register on lexical frequency (Additional Analysis: Lexical Frequency in CDS and ADS), (b) represents the effect of lexical frequency on phonological variation in morpho-phonological rules (Exp 2), (c) represents the direct effect of register on phonological variation (Exp 1), (c') represents the indirect effect of register on phonological variation, mediated by the frequency effect (Additional Analysis: Monosyllabic High Frequency Words in CDS and ADS, Common Lexical Items across CDS and ADS).

frequency word items to young children. The notion that enhanced pronunciation in CDS might be a secondary effect of lexical frequency or another linguistic characteristic of CDS is not entirely novel. Kalashnikova et al. (2017), for example, found acoustically exaggerated vowels in CDS compared to ADS, which they attribute to a shortened vocal tract due to a raised larynx rather than articulatory adjustments. Shortened vocal tract has an effect of increasing pitch, thus appearing smaller and non-threatening. They suggest that these effects have acquired a secondary function of enhancing phonological contrasts via the serendipitously exaggerated vowels. More recently, Cychosz et al. (2021) investigated acoustic and lexical characteristics of CDS to disentangle acoustic measures from lexical frequency and found that many acoustic characteristics such as vowel space, coarticulation, and speaking rate covaried with the lexical statistics. Their findings are similar to ours, except their focus of analysis is on the phonetic level, looking into sub-segmental and prosodic features, whereas our focus is on the more abstract phonological level and deals with segmental alternations.

Studies investigating the role of CDS in phonological learning by focusing on phonological alternations in English regressive place assimilation (e.g., gree[n] ~ gree[m] beans) in CDS and ADS seem to suggest the lack of phonological enhancement in CDS. For example, Buckler et al. (2018) did not find evidence for greater canonicality in CDS in the results of their perception experiments and acoustic analysis of elicited speech. Dilley et al. (2014) found some support for greater canonical clarity in CDS than ADS, but their results were based on read speech of 4 minimal pairs, and the distribution of non-canonical variants (i.e., assimilated, glottalized, deleted) did not differ between the two registers. English regressive assimilation is a phonetically motivated phenomenon; thus, higher usage-frequency of phrases might lead to a greater rate of assimilation applied. The studies mentioned did not take usage frequency into account when constructing their stimuli. As a result, the lack of phonological enhancement in CDS was observed under the same frequency condition for both CDS and ADS. These findings align with our results. The fact that we were able to replicate their null finding with phonetically unnatural morphophonological alternations supports the conclusion that phonological alternations are not simplified in CDS when all other conditions are the same.

Having established that CDS may not necessarily be less variable than ADS but may contain more canonical forms due to the use of high-frequency words, we can now explore the nature of the learning problem faced by children. As discussed in the introduction, the tutorial function hypothesis would predict reduced phonological variability in CDS. Under this view, children would first learn canonical forms of words and later learn about possible pronunciation variants. Alternatively, the affective function hypothesis would predict the presence of as many variants in CDS as in ADS, which would require children to learn lexical forms and variation processes simultaneously rather than sequentially. It turns out, however, that the mechanism behind the facilitative role of CDS in infants' language learning is more intricate than previously thought. Rather than providing simplified or enhanced phonological input, CDS facilitates infants' learning of the lexicon and phonological grammar through the use of high-frequency words, which are known to be resistant to change in phonological rules involving morphological analysis (Bybee, 2001). Our findings imply the need to move beyond simplistic hypotheses about child-directed input and phonological learning, and instead appreciate the intricate dynamics involved in these processes.

One limitation of our study is that the sex of the infants was not evenly distributed, as only 7 out of the 22 children were female. Previous studies have reported that mothers tend to treat boys and girls differently by providing more canonical variants to girls (Dilley et al., 2014; Foulkes et al., 2005). In Experiment 1, we observed a significantly

higher rate of canonical pronunciation in CDS within a sample that included a larger number of boys than girls. If the sex distribution in our sample had been more even, our results may have shown a somewhat stronger effect of register. There was indeed a tendency for mothers to use a higher rate of canonical forms to girls and to older children in our data, but a mixed effect logistic regression model on the canonicality of the target consonants with children's age, sex, and their interaction, and vowel as fixed effects and the participant and the item as random factors did not find statistically significant effects of age, sex, or their interaction. It would be beneficial to further investigate the issue of phonological variation as a function of child sex based on a larger data set with a more even sex distribution. Given the importance of lexical frequency in explaining phonological variation that the present study demonstrates, such a follow-up study would also have to examine if any difference in the rate of canonical forms in CDS addressed to boys and girls could be attributed to a gender-specific distribution of word items in the input.

In research involving young children, it is important to take into account the age of the child participants, because CDS is not constant but changes over the course of the child's development (Ko, 2012; Snow, 1977). Our study suggests that mothers of 11-month-old infants might provide enhanced evidence for the canonical pronunciation of a morpheme, by way of using high frequency words to their children. A naturally ensuing question is if mothers' enhanced pronunciation might continue beyond the pre-verbal and early speech period and, if so, for how long. This is an important question because the majority of our infant participants are still likely to be learning the phoneme categories, or have just begun learning to associate sound with meanings, and might not yet benefit from being exposed to evidence for phonological alternations. Note that our experiments were based on elicitation of target words. If our first experiment were conducted with older children, or even adults, we have reasons to believe that we would have found the same result because the register effect found in Experiment 1 seems to be an outcome modulated by lexical frequency. As shown in Experiment 2, high frequency words will demonstrate higher canonicality, regardless of the listener's age.

We suggest that the question of caregiver adaptation to child age is therefore essentially related to changes in lexical composition rather than phonology, at least in terms of morphophonological alternation. Caregivers may not necessarily adjust their phonology based on the child's level of phonological learning. However, they will provide appropriate levels of lexical items depending on the linguistic and cognitive development of their children (Rowe, 2012), which may have a serendipitous effect on facilitating infants' phonological learning. This conclusion underscores the importance of considering lexical frequency, and, in turn, using ecologically valid data collected in a naturalistic setting for a better understanding of the development and nature of CDS.

Conclusion

This study investigated how children might learn the underlying forms of a morpheme despite its varying phonological realizations in different morphophonological contexts, and explored the role the input might play in this process. Drawing on insights from developmental psychology, we tested the hypothesis that mothers might unintentionally reduce phonological variation and provide more canonical pronunciation to their children. To test this hypothesis, we examined the variation in Korean noun-stem final obstruents. This particular phenomenon was an ideal test case because of its phonetically unnatural nature, which allows for a clear differentiation of canonical forms from its variants.

Our findings indicate that the rate of canonical pronunciations is higher in CDS than ADS. Importantly, this difference is completely mediated by the tendency for CDS to use common, high frequency lexical items. According to the usage-based model of phonology, high-frequency words are more conservative and resist grammatical or analogical change involving the analysis of other forms as in morphophonological rules (Bybee, 2001; B. S. Phillips, 2001). By using simple and common words when speaking to children, caregivers inadvertently increase the proportion of morphemes that are pronounced canonically, thus facilitating infants' acquisition of underlying forms for morphemes and their development of phonological grammar. From a statistical perspective, therefore, there is no inherent improvement in pronunciation in CDS. From a sociolinguistic perspective, this finding is not surprising because what modulates the clarity of pronunciation is the formality of context. For example, in a formal setting like a job interview, speakers often enhance their pronunciation. However, CDS is generally spoken in an informal context, so it is not expected to show any enhanced pronunciation.

Thus, it turns out that an answer to the question of whether or not CDS plays a didactic role by providing an enhanced model to children is not a simple one. Does CDS help facilitate children's learning of phonological alternation by reducing variation in pronunciation? We can reasonably answer YES to this question based on the register effect observed in Experiment 1. However, do caregivers modify their phonological rule application to accommodate the developing phonological ability of their children? We can answer NOT NECESSARILY to this question as our results in the Additional Analysis section did not find evidence for the tutorial function hypothesis of CDS when frequency is controlled for. Does the lexical frequency in CDS influence phonological variation? Based on our findings in Experiment 2, we can answer YES to this question, but further research is needed to gain a broader understanding of the effects of lexical frequency in CDS on various phonological phenomena beyond morphophonology. Our study highlights the importance of considering language use when investigating the nature of CDS (Jones et al., 2023), and the need to move beyond a simplistic binary characterization of CDS and its role in children's language acquisition, and instead identify factors that make CDS an effective vehicle for delivering beneficial input to infants' language learning.

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