Infants discover English suffixes allomorph by allomorph

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Abstract:	Recent research has shown that 6-month-olds relate novel words suffixed with -s like babs that are embedded in passages, with just the stem bab, demonstrating an early sensitivity to morphological relatedness. This study builds on these findings by investigating the role of allomorphy in early morphological acquisition. We tested whether infants relate novel words suffixed with [-z] and [-s] allomorphs of the -s suffix and their stems. We find that English-learning 6-month-olds relate novel words suffixed with the [-z], but not [-s], allomorph with stems, providing evidence for an acquisition trajectory where infants discover morphemes one allomorph at a time.

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During acquisition, infants need to discover the smallest meaningful units in a language, morphemes. Crucial among these morphemes are inflectional suffixes like English *-s*, *-ed* and *-ing*. Discovering these suffixes is crucial as it represents a basic building block for syntax.

The process of learning morphological suffixes begins very early in infancy. Even before uttering their first words, infants begin to exhibit awareness of the form of suffixes in their native languages. English-learning 7.5-month-olds can use the suffix *-ing* to segment frequently occurring, familiar words from running speech (Willits et al., 2014). More recent work shows that even 6-month-olds extend this morphological awareness to nonce words. Specifically, Kim & Sundara (2021) show that English-learning 6-month-olds can relate a nonce word suffixed with *-s* like *babs* and *dops* with the corresponding stem *bab* and *dop* providing early evidence for morpheme decomposition.

However, there are multiple pronunciations of the English *-s* suffix. After a voiced sound like [n] or [d], it is pronounced [z], as in *buns* or *hides*, whereas after a voiceless sound like [t] or [k], it is pronounced [s] as in *eats* or *ducks*. Although Kim & Sundara (2021) demonstrated that English-learning 6-month-olds could relate nonce words suffixed with *-s* with just the bare stem, their experimental design did not distinguish the two different allomorphs: [-s] and [-z]. Of their four target words, two had final voiced consonants (*bab, kell*) while two had voiceless ones (*dop, teep*). In their experiments, half of the infants were familiarized with *babs* and *dops* while the other half were familiarized with *kells* and *teeps*, exposing all infants to one target nonce word with [-s] and one with [-z]. Consequently, it is unclear whether 6-month-olds can relate forms suffixed with [-z] as well as [-s] with stems because sufficiently strong success on one individual allomorph could have driven the results.

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In this paper, we investigate whether infants relate each of the two possible realizations of the English suffix *-s* by testing whether they relate CVC[z] (e.g., *babs*) and CVC[s] (e.g., *teeps*) sequences with their CVC stems. Through these experiments we seek to explore whether, during the earliest stages of acquisition, infants learn morphemes one allomorph at a time or through an alternative mechanism where multiple allomorphs are discovered simultaneously. *A priori*, there are three reasons why 6-month-olds may be sensitive to both allomorphs of *-s*, leading them to successfully relate both CVC[s] and CVC[z] sequences and their stems.

First, infants might use syntactic distributional cues to identify suffixed words. For instance, Mintz (2003) shows that infants can track *frequent frames* of the form A X B where X represents the target word and A/B are the words surrounding X. Some of these frames (e.g., "mama/mommy _ a") tend to contain suffixed forms in infant-directed speech, making them highly informative. If infants observe that most words in a given frame are suffixed, they may infer that a novel word in that context—regardless of whether it ends in [-s] or [-z]—likely includes a morpheme boundary.

Second, infants may not be able to distinguish the [-s] and the [-z] allomorphs. For instance, we know that discrimination of voicing differences in codas is challenging for adults (Chong & Garellek, 2018) and infants (Eilers et al., 1977), likely because English voiced consonants are often devoiced or weakly voiced in final position. Due to the perceptual similarities in word-final [s] and [z], infants may not distinguish the [-s] and [-z] allomorphs in CVC[s] and CVC[z] sequences, leading them to relate both suffixed forms with stems.

Third, infants may discover morphemes by detecting overlap in form and meaning (Baayen et al., 2016). Even at 6-months, English learning infants' vocabularies tend to have some plural nouns like *legs*, *hands* along with their singular counterparts like *leg, hand*

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(Bergelson & Swingley, 2012). Thus, by attuning to overlap in the form and meaning of pairs such as *leg, legs*, they may successfully relate suffixed nonce words with both the [-s] and [-z] allomorphs with stems.

There are also strong arguments suggesting infants are more likely to relate only CVC[z] sequences to their stems. First, distributional evidence in infant-directed speech favors [z] as an English suffix. The [-z] allomorph is more frequent, combining with more unique words than [-s] in infant-directed speech as shown in Table 1. In the 0.5 million word Brent corpus (Brent & Siskind, 2001), , [-z] occurs with more than twice as many word types as [-s] (878 vs. 342 types). Kim & Sundara (2021) argue that suffixes with the highest type frequency regardless of meaning, function, or word class are discovered first by infants. At 6 months, they relate stems only to forms suffixed with the most frequent suffix (*-s*), and by 8 months, to forms with the next most frequent (*-ing*). Given the higher type frequency of [-z], infants might discover it earlier and therefore relate CVC[z] forms more reliably to CVC stems.

Allomorph	**Word Class**	**Function**	**Type frequency**
[-z]	Verb	3rd singular present	148
	Noun	possessive	183
	Noun	plural	547
Total [-z]			*878*
[-s]	Verb	3rd singular present	100
	Noun	possessive	25
	Noun	plural	217
Total [-s]			*342*
[-ɪz]	Verb	3rd singular present	27
	Noun	plural	66
Total [-ɪz]			*93*

Table 1. Frequency of the allomorphs of *-s* in the ~0.5 million word Brent corpus

Second, even though [s] is more frequent in word-final position than [z], [z] is far more likely to be a suffix than [s]. In the Brent corpus, 85% of word-final [z]'s are suffixes compared

to only 55% for word-final [s] . Thus, simply by inserting a morpheme boundary before every occurrence of word-final [z], the learner can achieve a high accuracy in morpheme decomposition.

Finally, phonotactics provide a third reason to expect decomposition for CVC[z] but not CVC[s] sequences. In English, sequences such as [bz] and [lz] as in *ba**bs*** and *ke**lls*** are not allowed within a morpheme. This means that if the infant does not decompose [bæbz] and [kɛlz] into stem+suffix sequences ([bæb+z] and [kɛl+z]), they are left with a disallowed sequence. On the other hand, CVC[s] sequences are well-formed both as unsuffixed (e.g. *box*) and suffixed sequences (*e.g. kick+s*). That is, CVC[z] sequences in infant-directed speech have absolute phonotactic cues to morpheme decomposition as they obligatorily signal a morpheme boundary, whereas CVC[s] sequences only offer gradient cues to decomposition as both suffixed and unsuffixed forms are possible. This distinction is clearly seen in the Brent corpus. There are 85 different CVC[z] sequences in the corpus all of which are suffixed CVC+[z] sequences. However, the same is not true with CVC[s] sequences. There are 54 suffixed CVC[s] sequences and 17 unsuffixed ones, making the decomposition of such sequences more uncertain. CVC[z] forms, then, provide absolute cues to morphological boundaries, whereas CVC[s] forms only offer probabilistic ones.

Indeed, we know based on evidence from Mattys & Jusczyk (2001) that English-learning 9-month-olds successfully extract novel words from running speech when embedded in contexts with absolute phonotactic cues where failing to segment the word would create illegal or low frequency CC clusters, like [fh] in the sequence *gaffe hold*. However, they fail when the novel words are embedded in contexts with gradient phonotactic cues where a word boundary is optional, like [ft] in the sequence *gaffe tine*.

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In summary, if infants primarily rely on syntactic distributional cues or semantic and phonological overlap to perform morpheme decomposition, then we expect their behavior with respect to the two allomorphs of *-s* to be identical. If, instead, they are sensitive to the higher frequency of the [-z] allomorph, the higher likelihood of [z] being a morpheme, and absolute phonotactic cues, then we expect that they will successfully decompose CVC[z] sequences but not CVC[s] sequences.

To test morphological decomposition by 6-month-olds, we familiarized infants with either *babs* and *kells* ([-z] allomorph) or *dops* and *teeps* ([-s] allomorph) embedded in passages. Then, infants were presented with all four stems (*bab, kell*, *dop, teep*) produced in isolation in the test phase. Because we used nonce targets as verbs during familiarization, infants had no access to semantic cues as events are challenging for infants to relate to meanings (see Golinkoff & Hirsh-Pasek, 2006 for an overview). We further controlled the syntactic distributional information in the surrounding sentence context in passages, so that they were comparable for [-z] and [-s].

If infants do not decompose the potentially suffixed sequences (e.g., *babs, kells*), then all four stems (*bab, kell*, *dop, teep*) should be novel with no observable differences in listening times between *bab, kell* and *dop, teep*. If infants decompose the potentially suffixed sequences (e.g., *babs, kells*), then two of the stems should be familiar (e.g., *bab, kell*) and two should be novel (e.g., *dop, teep*). Thus, successful morpheme decomposition can be inferred if infants' listening times are significantly different for stems of the suffixed words presented in the familiarization phase compared to completely novel stems.

If infants discover [-s] and [-z] allomorphs at the same time, then we expect significant differences in listening time to potentially familiar compared to novel stems when infants are

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familiarized with either *babs*, *kells* or *dops*, *teeps*. However, if early in acquisition infants discover suffixes allomorph by allomorph, then we expect significant differences in listening time only when infants are familiarized with *babs* and *kells*.

Method

Participants

The data from 63 (33 for the *dops, teeps* condition; 23 female, 40 male) full-term 6-month-olds (mean = 187 days, range 168-209) were included. Only infants with at least 90% English input were included (mean = 98%, range 90-100) as determined based on a detailed parental language questionnaire (Sundara & Scutellaro, 2009). Furthermore, none of the infants had a history of speech, language, or hearing difficulties, and were in good health on the day of testing. Additional infants were tested but not included in the final dataset because they did not complete testing due to fussiness (n = 8), failure to look at the lights (n = 4), exceeding the maximum experiment time of 10 minutes (n = 5), technical difficulties (n = 1), or having listening times more than two standard deviations away from the mean (n = 1).

Stimuli

The stimuli used were identical to those in Kim & Sundara (2021) except the two sub-conditions were re-arranged such that the participants in one sub-condition would only be familiarized with nonce words suffixed with the [-z] allomorph (*babs* and *kells*) and those in the other sub-condition would only be familiarized with nonce words suffixed with the [-s] allomorph (*dops* and *teeps*). Note that all four different suffixed nonce words are CVCC's, and have different vowel qualities.

The stimuli were recorded by a 25-year-old female native English speaker from Southern California who was unfamiliar with the purpose of the experiment. She was instructed to read the

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passages in an animated voice as if she were talking to a preverbal infant. Six four-sentence passages containing the suffixed novel words and four lists containing 15 repetitions of the stems in isolation were used. In the passages the suffixed novel words were preceded by *mommy* or *mama* - to help with word segmentation (Bortfeld et al., 2005). Detailed acoustic analyses and passages are reported in Kim & Sundara (2021) and presented on the project OSF site for completeness.

Due to the particular passages used in the experiment, distributional information from the surrounding words was at best uninformative to determine whether or not an intervening form is suffixed but, in fact, slightly favored an unsuffixed form (see the project OSF site for statistics).

Procedure and Design

The Headturn Preference Procedure was used to test infants (Jusczyk & Aslin, 1995; Kemler Nelson et al., 1995). Whether *mommy* or *mama* passages were used was determined by which form was used at home. Testing took about 10 minutes per participant. Each infant sat on their caregiver's lap facing the center panel of a three-sided pegboard booth with lights attached to each of the three sides. The caretaker and experimenter wore headphones with music playing to prevent them from influencing the infant.

On each trial, the light on the center panel flashed to draw the infant's attention. Subsequently, a light on one of the side panels began to flash to attract the infant's attention towards that panel. Once the infant was focused on the light, auditory stimuli played from a speaker just below the light. The experimenter observed the infant through a video feed and recorded the direction and duration of the infant's head turns. Presentation of auditory stimuli was completely contingent on infant looking behavior, and thus served as a proxy for listening time - the primary variable of interest in this study.

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In the experiment, the infants were first familiarized with two suffixed target words (either *babs, kells* or *dops, teeps*, counterbalanced) embedded in passages until they accumulated 45 seconds of listening time to each of the two passages. Afterwards, in the test phase, the infants were presented with potentially familiar and novel, isolated stems (*bab, kell, dop, teep*) in three blocks for a total of 12 trials. Significantly different listening times to potentially familiar stems compared to novel stems provide evidence that infants successfully related suffixed words to stems.

Analysis

The listening times were log-transformed as they were not normally distributed (Csibra et al., 1999), although we present raw listening time data in figures for ease of comparison to previous research. The mean of the log-transformed listening times was 2.16 (SD = 0.52). The pattern of results was the same when raw listening time data was used as a dependent variable. We used Bayesian mixed effects models to analyze listening time data; we did this in order to be able to interpret results in case infants failed to distinguish the potentially familiar and novel stems. The fixed effects included the between-subjects variable Familiarization Condition ([-z] allomorph: *babs*, *kells* or [-s] allomorph: *dops*, *teeps*), the within-subjects variable Block (1st, 2nd, or 3rd) - to control for the effects of repeated exposures to the isolated novel words on listening times, and Trial Type (potentially familiar vs. novel) and all interactions. The model also included a random intercept for Subject to model differences in the baseline listening times along with random slopes for Trial Type by Subject and Block by Subject to model individual differences in relative differences in listening times.

We used the *brms* package (Bückner, 2017) to fit the models with a default prior for the intercept and a Normal (0, 1) prior for the coefficients. The Normal (0,1) prior for the

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coefficients corresponds to no prior belief (hence a coefficient centered at 0) that there is any effect of Familiarization Condition, with the bulk of the values in the range of values between -2 and 2. To assess the robustness of our findings to prior specification, we re-ran the model using weaker and more diffuse priors (e.g., Normal(0, 5) and Normal(0, 10)). Results for the sensitivity analyses are reported on the project OSF page; they were consistent across models, with all posterior estimates and credible intervals remaining stable, indicating that our conclusions are robust to reasonable variations in prior choice. Thus, we only report results from the original model (See Van de Schoot et al., 2021 for an overview on choosing different parameter values). From the posterior distribution on each of four chains 10,000 samples were drawn with the first 1,000 discarded for warm-up. To prevent divergent transitions when sampling, we set the *adapt_delta* parameter in *brms'* No U-Turn Sampler to 0.9999. In addition, planned comparisons were performed using the *emmeans* package in R.

We report the median values of the coefficients (β) of the relevant predictors along with their 95% Credible Intervals (henceforth, 95% CrI). If the 95% CrI includes 0, we also include the probability of an effect on one side of 0, regardless of the magnitude (referred to as *p*-direction). The value for *p*-direction ranges from 0.5, indicating equal probabilities of an effect above or below 0, to 1 when all of the posterior samples for the coefficient lie on one side of zero, indicating a strong directional effect.

Results

The listening time data for the experiment are shown in Figure 1. As expected, there was a credible main effect of Block (Block 2: β = -0.19, 95% CrI [-0.31, -0.08]; Block 3: β = -0.28, 95% CrI [-0.40, -0.17]), confirming that listening time reduced across the three blocks. There was also a credible main effect of Familiarization Condition (β = 0.16, 95% CrI [-0.04, 0.36], *p*-

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direction = 0.95). Crucially for our hypotheses, there was a credible interaction of Trial Type and Familiarization Condition (β = -0.18, 95% CrI [-0.40, 0.04], *p*-direction = 0.94). That is, we can be 94% certain that the effect of the interaction was negative. This shows that infants behaved differently when tested on the [-z] allomorph (*babs*, *kells* condition) and the [-s] allomorph (*dops*, *teeps* condition).

Planned comparisons showed that the main effect of Trial Type was credible for the [-z] condition (β = -0.09, 95% CrI [-0.19, 0.00], *p*-direction = 0.97) but not the [-s] condition (β = -0.01, 95% CrI [-0.11, 0.08], *p*-direction = 0.62). In the [-z] condition, 22/30 participants showed a novelty preference, whereas 17/33 participants showed a novelty preference in the [-s] condition.

Unlike in frequentist analysis, where lack of significance cannot be taken as evidence that there was no effect, in Bayesian Analysis, because the *p*-direction for the coefficient estimate for the [-s] condition was 62%, we know that the coefficient is about equally likely to be positive or negative. That is, we can be sure that there was no evidence that infants distinguished the two trial types in the [-s] condition.

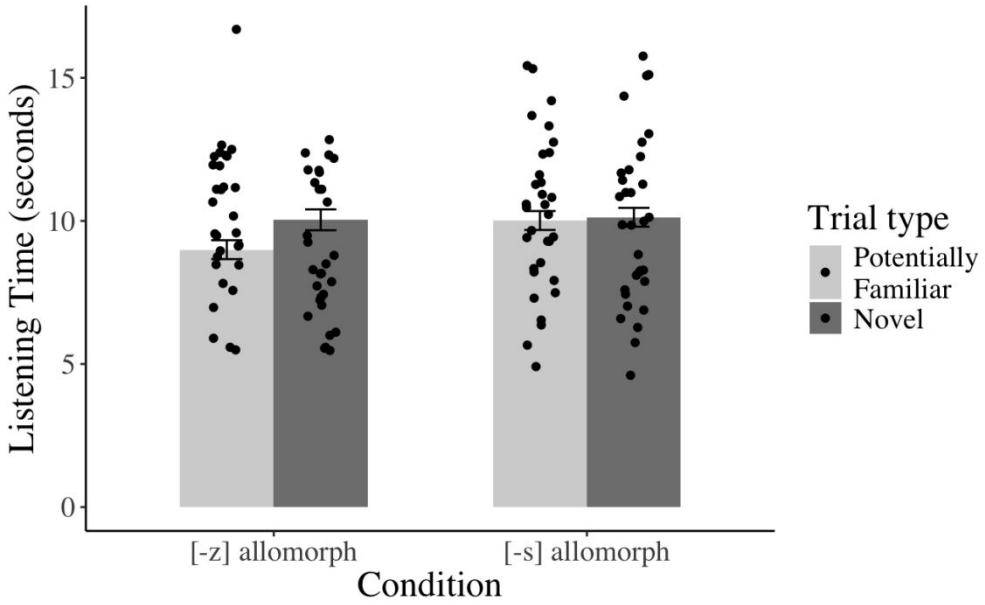

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Figure 1. Mean listening times (in seconds) by condition and trial type. Dots represent data from individual subjects.

Thus, infants listened credibly longer to novel stems compared to potentially familiar stems when familiarized with suffixed forms containing [-z] but not [-s]. Note that the direction of listening preference here - novelty, is different from that reported in Kim & Sundara (2021). We speculate that this is consistent with the relative ease of the task here a la Hunter & Ames (1988), because infants were only tested on the [z] allomorph. In sum, 6-month-olds only displayed sensitivity to the [-z] allomorph of the English *-s* suffix as they related suffixed novel forms such as *babs* with its stem *bab* but not suffixed novel forms such as *dops* with its stem *dop*.

Discussion

In this paper, we investigated the ability of monolingual English 6-month-olds to decompose nonce words suffixed with *-s* into stem+suffix sequences. In one condition, infants were familiarized with nonce stems suffixed with the [-z] allomorph, in the other condition, with the [-s] allomorph. Through these experiments, we sought to address whether infants discover minimally different allomorphs, one by one, or simultaneously.

Our results are consistent with an account where infants' early morphological representations are allomorph-specific. English-learning 6-month-olds successfully related CVC[z] sequences with their stems but not CVC[s] sequences. The fact that infants successfully decompose [-z] but not [-s] is incompatible with the idea that infants solely rely on phonological overlap to relate forms; there is comparable overlap between CVC[s] and CVC[z] forms and their stems, yet infants only succeeded in one condition. These results also indirectly demonstrate that English-learning 6-month-olds are able to distinguish word-final [s] and [z] as

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they behave differently in the two conditions, adding to the small literature on infants' detection of word final segmental contrasts (e.g., Fais et al., 2009).

What might explain these results where infants become sensitive to one allomorph before the other? As previously discussed, one possibility is that infants as young as 6-months are sensitive to phonotactic cues when performing morpheme decomposition. This is supported by the fact that it is the condition with absolute phonotactic cues (CVC[z]; as failing to insert a morpheme boundary leads to a phonotactically illicit cluster) where the infants succeeded. When the phonotactic cues were gradient (CVC[s]), they failed to relate the suffixed and stem forms.

However, phonotactics cannot be the sole factor determining infant morpheme discovery. As with CVC[s] sequences, neither CVC[t]/CVC[d] sequences (corresponding to the English *-ed* suffix) nor CVC[ɪŋ] sequences (corresponding to the English *-ing* suffix) create phonotactically illicit clusters. Thus, a learner relying solely on phonotactic cues to discover morphemes should not treat any of these suffixed sequences differently. Nevertheless, Kim & Sundara (2021) show that infants actually do behave differently with the two suffixes, discovering the *-ing* suffix at 8-months, before they have discovered the *-ed* suffix.

Kim & Sundara (2021)'s results showing that 6-month-olds fail to relate CVC[ʃ] sequences to CVC stems provide further evidence against the proposal that infants discover suffixes by relying solely on phonotactic cues. In English sequences such as [bʃ], [lʃ] and [pʃ] as in *ba**bsh*** and *ke**llsh,** do**psh** and tee**psh*** are not allowed within a morpheme. If infants discover suffixes merely by positing morpheme boundaries when presented with absolute phonotactic cues, they should successfully decompose both CVC[ʃ] and CVC[z] sequences. Thus, 6-months-olds failure to decompose sequences like [babʃ], combined with their success decomposing

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sequences like [babz] indicates that phonotactic cues are not sufficient for infants to discover suffixes.

It is also unlikely that 6-month-olds were sensitive to *bab* because they segmented the [s]/[z] as the onset of a following word (e.g., segmenting "Mommy babs if" as "Mommy bab sif"). Firstly, in half the familiarization sentences, the suffixed forms occurred in utterance-final position, marked by a clear prosodic boundary—both a pitch drop and silence—making such syllabification impossible. Moreover, /s/ (along with /t/ and /d/) is a much more frequent word onset in English than /z/. If infants simply inserted a boundary after the stem based on phonotactic probabilities, we would expect them to relate /ps/ with /p/ more easily than /bz/ with /b/. Yet, our results show the opposite: infants succeeded with /bz/ but not with /ps/.

Indeed, Breiss et al. (2025) propose a computational model with an alternate heuristic to predict the observed order of acquisition of English suffixes. Their model utilizes how often a sequence occurs at the end of the word. For example, [z] frequently occurs at the end of words (e.g., *buns, hides*), making it more likely to be a suffix. Their model is also sensitive to how often a sequence occurs after a stem which the infant has observed as an independent word (see Hammarström, 2006 for a similar proposal in natural language processing). Thus, hearing both the sequences *run* and *runs* supports [-z] being a morpheme. Taken alone, neither of these metrics correctly predict the order of acquisition of various English morphemes. Only by combining both can they arrive at their best-performing model which mirrors the actual order of acquisition of English suffixes. Their model also predicts, as we have found in our experiment, that the [-z] allomorph will be discovered before the [-s] allomorph.

Ultimately, our results demonstrate that morphological representations are detailed early in development. English-learning 6-month-olds have distinct representations for the allomorphs

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[-z] and [-s] as evidenced by their success in decomposing CVC[z] but not CVC[s] sequences. Importantly, this sensitivity is not tied to a specific meaning, function, or word class. Rather, infants initially develop sensitivity to forms (e.g., [z]) without yet differentiating among their various grammatical uses (e.g., plural, possessive, or 3rd person singular; Sundara, 2022). In this sense, infants' initial knowledge of suffixes is better characterized as morph-specific rather than allomorph-specific.

This should perhaps not be surprising if young infants discover suffixes before they have access to meaning or word class, meaning that they have no information which would lead them to treat the two morphs equivalently. Instead, the frequency of individual morphs itself is a strong predictor of early morpheme decomposition. 6-month-olds only related novel words suffixed with the more frequent form [-z] of the English *-s* suffix to stems but not novel words suffixed with the less frequent [-s]. Whether infants learn to group allomorphs later in acquisition using semantics or syntactic distributions remains to be determined.

In summary, monolingual English learning 6-month-olds can relate novel CVC[z], but not CVC[s], sequences with their stems. Our findings provide evidence for an acquisition trajectory where detailed morphological representations are discovered one-by-one early in development, not simultaneously.

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