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RESEARCH ARTICLE

The competition–compensation account of developmental language disorder

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Abstract

Children with developmental language disorder (DLD) regularly use the bare form of verbs (e.g., *dance*) instead of inflected forms (e.g., *danced*). We propose an account of this behavior in which processing difficulties of children with DLD disproportionally affect processing *novel* inflected verbs in their input. Limited experience with inflection in novel contexts leads the inflection to face stronger competition from alternatives. Competition is resolved through a compensatory behavior that involves producing a more accessible alternative: in English, the bare form. We formalize this hypothesis within a probabilistic model that trades off context-dependent versus independent processing. Results show an over-reliance on preceding stem contexts when retrieving the inflection in a model that has difficulty with processing novel inflected forms. We further show that following the introduction of a bias to store and retrieve forms with preceding contexts, generalization in the typically developing (TD) models remains more or less stable, while the same bias in the DLD models exaggerates difficulties with generalization. Together, the results suggest that inconsistent use of inflectional morphemes by children with DLD could stem from inferences they make on the basis of data containing fewer novel inflected forms. Our account extends these findings to suggest that problems with detecting a form in novel contexts combined with a bias to rely on familiar contexts when retrieving a form could explain sequential planning difficulties in children with DLD.

KEYWORDS
child language disorder, fragment grammars, hapax legomena, nonparametric Bayesian models, SLI

Research Highlights

- Generalization difficulties with inflectional morphemes in children with Developmental Language Disorder arise from these children's limited experience with novel inflected forms.

- Limited experience with a form in novel contexts could lead to a storage bias where retrieving a form often requires relying on familiar preceding stems.
- While generalization in typically developing models remains stable across a range of model parameters, certain parameter values in the impaired models exaggerate difficulties with generalization.
- Children with DLD compensate for these retrieval difficulties through accessibility-driven language production: they produce the most accessible form among the alternatives.

1 | INTRODUCTION

A hallmark of developmental language disorder (DLD) in English-speaking children is inconsistent use of inflectional morphemes in appropriate contexts. Of all the inflectional morphemes that cause difficulty for these children, the regular past tense suffix *-ed* is one of the most prevalent and is produced much less accurately by children with DLD compared to both their age-matched and younger typically developing (TD) peers (see Krok & Leonard, 2015, for a review). Although these errors are also observed in the productions of TD children (Bybee & Slobin, 1982; MacWhinney, 1978; Marcus et al., 1992), consistent use of the past-tense morpheme occurs at a later age for children with DLD and seems to coincide with sentence structures with higher complexity. Crucially, the majority of errors for children with DLD in English involve producing the bare form instead of the inflectional suffix, as in *dance* instead of *danced*. Verb agreement errors such as *they am laughing* and insertions such as *I likes milk* are rarely observed (Leonard, 2014, pp. 82–83).

Here we propose a new account of children's difficulty with inflectional suffixes: the *Competition–Compensation Account*. The Competition–Compensation Account attributes the cause of morphological impairments to the disproportionate effect of processing difficulties on novel inflected forms with a suffix, i.e., combinations of stems and suffix that are new to the learner. Less experience with novel inflected forms reduces the suffix's productivity. The competition component maintains that a verb produced with a weakly productive suffix faces stronger competition from alternatives. Compensation is a mark of accessibility-driven language production (Harmon & Kapatsinski, 2017): bare form is produced because it is more accessible than other alternatives.

A number of processing-based accounts of DLD have been proposed throughout the years. Many of these accounts identify the locus of the problem in processing deficits: deficits in working memory or processing speed are hypothesized to interfere with learning language in general, and morphosyntactic generalizations in particular (e.g., Bishop, 1994; Ellis Weismer & Hesketh, 1996; Hoeffner & McClelland, 1993; Joanisse & Seidenberg, 1998; Kail, 1994; Leonard, 1989; Tallal & Piercy, 1973). Another account, the Procedural Deficit Hypothesis, where the ability to learn cognitive skills including language is impaired due to the atypical development of memory systems involved in procedural learning (Ullman & Pierpont, 2005), has been framed as an alternative to processing accounts. Related work investigating procedural learning has found that sequential learning in children with DLD is impaired (e.g., Hsu & Bishop, 2014; Krishnan et al., 2016). The Competition–Compensation Account highlights a potential link between processing-related impairments and procedural knowledge by proposing that experiencing a form in novel contexts supports sequential planning of that form.

We use the probabilistic model proposed previously by O'Donnell (2015) to investigate the differential effects of processing in TD and DLD. Because our hypothesis is that typical development and DLD differ in processing of novel inflected forms, we implement processing difficulties by omitting from the model's input the inflected forms that occurred only once. Analyzing the model and its impaired counterparts, we demonstrate how reduced experience with novel inflected verbs could influence parsing and planning of the inflection over time, in turn impeding its generalization. First, novel inflected forms in the input encourage the use of a suffix independently of the preceding stem contexts, reducing overreliance on storing and retrieving inflected verbs as an unanalyzed whole. If the availability of novel inflected verbs in the input is compromised—as proposed by our account—this balance shifts, weakening the context-independent suffix representation. Second, we incorporate a bias into our model that is independent of the input, but changes the degree to which the model relies on storage and retrieval of unanalyzed chunks. We show that this bias has a more detrimental effect on the performance of the impaired model.

The remainder of the paper is structured as follows. We begin by describing our theoretical account in the context of the literature on DLD, then introduce our model and report on a simulation that tests its behavior when trained on input from CHILDES (MacWhinney, 2000) that represent typical versus atypical processing. Then, using the model's representations, we demonstrate how depriving the DLD model of novel inflected forms with the suffix could bias the model towards a set of representations that lead to difficulty accessing the suffix independently of its preceding context (the preceding stem). A second simulation shows that the extent of such bias in parsing the input corresponds to varying levels of difficulty with generalization, an important observation in the DLD population. We conclude by discussing the implications of our account.

2 | THE COMPETITION–COMPENSATION ACCOUNT

The Competition-Compensation Account is based on the premise that learning the degree of productivity of a morphological process is a probabilistic inference problem. The child uses the input available to make an inference about the productivity of a morpheme. The inference guides prediction regarding the applicability of that morphological process in the future (see also O'Donnell, 2015). If this inference is made on the basis of impoverished data—that is, input with a reduced number of novel items—the result is a morpheme with a lower production probability. Consequently, the child who infers a lower production probability for a morphological process faces stronger competition in selecting between that process and other competing alternatives.

If the competition is too difficult to resolve on the fly, the child resorts to producing the next best available alternative. We argue that in the case of the English verb paradigm, this alternative is the bare form of the verb (e.g., *dance*). In English, the bare form has higher frequency relative to inflected forms, and as a result, is highly accessible during production (Harmon & Kapatsinski, 2017; Oldfield & Wingfield, 1965). It also has high phonological and semantic overlap with the inflected form through sharing a stem. Form accessibility and high semantic overlap render the bare form a strong competitor. The Competition–Compensation Account characterizes the production of the bare form as the child's compensatory behavior.

An existing influential account of DLD that highlights the role of compensation in morphological deficits is the Procedural Deficit Hypothesis (Ullman & Pierpont, 2005). In the Procedural Deficit Hypothesis, morphological problems are rooted in a deficit of the procedural memory system. The occasional appearances of inflectional morphemes are attributed to a compensation strategy whereby language-impaired individuals produce an unproductive rule by resorting to memorization using the declarative memory system. However, this account does not make clear why the declarative system only sometimes compensates for the procedural system and, if the compensatory strategy is always available, why the production of inflected verbs is not always successful (see Thomas, 2005, for a discussion). Overall, under the Procedural Deficit Hypothesis, the availability of the declarative system as a compensatory mechanism seems to demand its own investigation of morphological deficits independent of the procedural system (see Lum & Conti-Ramsden, 2013; Lum et al., 2015; Ullman & Pullman, 2015, for related work).

Unlike the Procedural Deficit Hypothesis wherein the compensatory strategy is posited to account for the occasional *appearance* of inflectional morphemes, in the Competition–Compensation Account, the compensatory behavior results in a *failure* to produce the inflected item, owing to its function of delivering semantics as opposed to form. This means that, rather than seeking a solution to the problem of producing the correct form, the system prioritizes a solution to expressing the planned meaning. This results in the production of highly similar forms that are more accessible, i.e., easier to produce, such as the production of the bare form instead of the past tense in English.

But how about the occasional appearance of inflectional suffixes? As mentioned earlier, these suffixes are not entirely absent in the speech of children with DLD (e.g., Marchman et al., 1999). We suggest that the reason inflectional suffixes appear only occasionally is that weakly productive suffixes face strong competition from other alternatives, such that the correct form only sometimes overcomes competition. As a result, these morphemes are sometimes produced successfully, but fail to apply on a regular basis.

The Competition–Compensation Account adopts the proposal that experiencing *novel* inflected verb types contributes to morphological productivity. The number of distinct stems co-occurring with a suffix, also known as its type frequency, has been proposed as a major determinant of productivity—the ease by which a morphosyntactic pattern applies to novel instances (Bybee, 1985, 1995; MacWhinney, 1978; O'Donnell, 2015; Yang, 2016). *Hapax legomena*—words that occur only once in a sample—provide a measure of how often *novel* types are encountered and have been used to estimate differences in productivity of different morphological processes (e.g., Baayen, 1992, 1993, 1994, 2001; Baayen & Renouf, 1996). How often hapax legomena appear with a morphological process over time is a measure of how fast that category is expanding, and how productive it is (Baayen, 2009). For example, English speakers are more likely to use the suffix *-ness* to create a noun from an adjective than the suffix *-th*, meaning that *-ness* is more productive than *-th*. Accordingly, the distribution of *-ness* includes many more hapax legomena with *-ness*.

The Competition–Compensation Account proposes that children with DLD experience fewer hapax legomena with *-ed* compared to their TD peers. Reduced exposure to *-ed* hapaxes weakens the productivity of *-ed*. For a form to be productive, it must be parsed out of the contexts in which it has been experienced (Hay & Baayen, 2002) and must be accessible independently of those contexts (Harmon & Kapatsinski, 2021). While applying a suffix to hapax legomena requires parsing the suffix independently of the stem, its *repeated* application to a small number of stems results in chunking the suffix with those stems (e.g., Bybee & Brewer, 1980; Kapatsinski, 2010; Stemberger & MacWhinney, 1986). If the input comprises many high frequency items with a suffix, the suffix remains unparsed and unanalyzed to the learner on many instances of occurrence. As the child infers the productivity of the suffix, these items do not contribute to the estimation, so the child assigns a lower probability to a context-independent representation of the suffix. A lower probability, in turn, limits the suffix's future applicability to unfamiliar and novel stems. Behaviorally, the child may experience more competition especially in unfamiliar and novel contexts as retrieving the suffix is more difficult. The result is an overreliance on high frequency forms with that suffix, as well as a failure to retrieve the suffix, both of which are observed in the speech of children with DLD.

How might the novel application of a suffix be vulnerable to processing difficulties in children with DLD? There are at least two possibilities, one based on how the input is processed and the other based on the quality of the input itself. These two possibilities are not mutually exclusive, but we argue that the major influence comes from processing difficulties of children with DLD.

First, children with DLD are slower to learn novel words. Studies on the acquisition of novel words show that in both comprehension and production (e.g., Kan & Windsor, 2010), children with DLD require more exposure than their TD peers to achieve similar learning outcomes (e.g., Alt et al., 2004; Oetting et al., 1995; Windfuhr et al., 2002). Furthermore, children with DLD not only have difficulty with initial encoding of words (McGregor et al., 2017), but are also more prone to forgetting what they recently learned (Rice et al., 1994; Riches et al., 2005), both of which may jeopardize learning of novel instances. Overall, encoding difficulties combined with auditory processing difficulties of nonsalient inflections may lead to special difficulties with processing novel inflected forms.

A second possibility is that children's processing difficulties, along with comorbid conditions such as ADHD (Tirosh & Cohen, 1998), may limit their exposure to novel inflected forms. Although we do not propose differences in the input as the major cause of DLD, we entertain the possibility that they may play a partial role in reducing the number of novel inflected forms addressed to the child. A few findings suggest that caregivers' productions may be affected by their attempt to accommodate to children (Conti-Ramsden & Dykins, 1991) by relying on repetitions or imitations of utterances (Horsborough et al., 1985) as well as limiting lexical diversity in their speech when detecting comprehension difficulties (Van Kleeck & Carpenter, 1980). In addition, the emergence of first word in children with DLD is delayed—23 months on average in DLD versus 11 months on average in typical development (see Leonard, 2014, for a review)—which can delay and in turn reduce the number of novel items addressed to the child. Here, we simply ask if—regardless of the mechanism responsible for limiting children with DLD's experience with novel inflected types—learning from fewer novel inflected types results in generalization difficulties.

3 | THE MODELING APPROACH

We use Fragment Grammars (O'Donnell, 2015), a nonparametric Bayesian model, to implement our account computationally. Fragment Grammars is an ideal model for capturing our phenomenon of interest because it represents generalizations at different levels of specificity, ranging from a context-dependent representation of a form, where the form is chunked and stored with the preceding context, to a context-independent representation of a form, or a fragment with a variable slot. We illustrate these representations in Figure 1. Fragment Grammars has successfully accounted for findings on TD children's patterns of morphological use in past work (O'Donnell, 2015), making it a promising choice for studying atypical language development.

The underlying recursive structure of a FG is specified by a Context-Free Grammar. The Context-Free Grammar for our current data on English verbs expands the nonterminals VERB, STEM, and INFLECTION. The probabilities associated with each nonterminal are drawn from a Dirichlet distribution with parameter $\vec{\pi}$, yielding a hierarchical

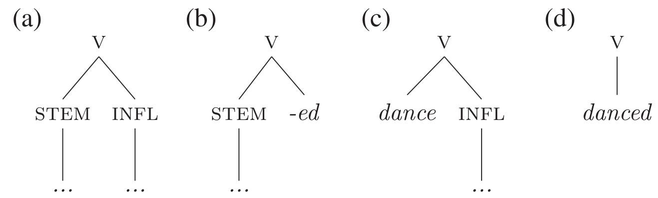

FIGURE 1 All possible ways to generate a tree. Panel (a) shows full computation, where generating a verb in past tense would require accessing both STEM and INFLECTION nonterminals. Dots in terminal positions indicate empty slots that need to be filled for a form to be generated. In (b), generating a verb with *-ed* requires accessing the stem, but not the suffix, resulting in context-independent representation of *-ed*. The fragment in (c) allows generating an inflected form of a verb such as *danced* without accessing the STEM nonterminal. Panel (d) shows a frozen fragment where parsing or generating a verb that frequently occurs with *-ed* does not require accessing the STEM or INFLECTION nonterminals, resulting in a context-dependent use of *-ed*.

Dirichlet-Multinomial pseudocount for each nonterminal,

$$\vec{\theta} \sim Dirichlet(\vec{\pi}). \qquad (1)$$

The expansion of nonterminals in FG is adapted through the implementation of the Pitman–Yor (PY) process (Pitman & Yor, 1997). This adaptation process incorporates *stochastic memoization*, which allows frequently reused sequences of computations to be stored and reused (Goldwater et al., 2011; Johnson et al., 2007; O'Donnell, 2015). Figure 1 shows all possible ways a regular past-tense form *danced* can be built from memoized and nonmemoized fragments. The tree in (a) shows derivation using full computation, where generating a verb with *-ed* would require accessing both STEM and INFLECTION nonterminals. If the recurrence of two computations is high, they memoize into one computation. For example, if *dance* and *-ed* co-occur frequently, a memoized fragment, *danced*, is created and directly available within the VERB nonterminal (Figure 1d), eliminating the need to use three separate rules (V → STEM INFLECTION, STEM → *dance*, and INFLECTION → *—ed*) when generating the verb *danced*. This results in a frozen fragment or an unanalyzed chunk, a morphologically complex word stored as a whole with no internal structure. When the representation in (d) is used, *-ed* is generated in a context-dependent manner as it is not possible to retrieve *-ed* without retrieving the preceding stem context.

Depending on how often each rule in a tree is reused, only parts of the computation may be memoized. Panel (b) exemplifies this possibility, showing that when a good number of stems occur with *-ed*, only the computation involving INFLECTION is memoized. In this fragment, henceforth *the past-tense fragment*, generating a verb with *-ed* only requires accessing the STEM nonterminal. The past-tense fragment denotes a context-independent activation of *-ed*.

4 | SIMULATION I

To test the predictions of the Competition–Compensation Account, we first wanted to know whether problems with detection of a form in

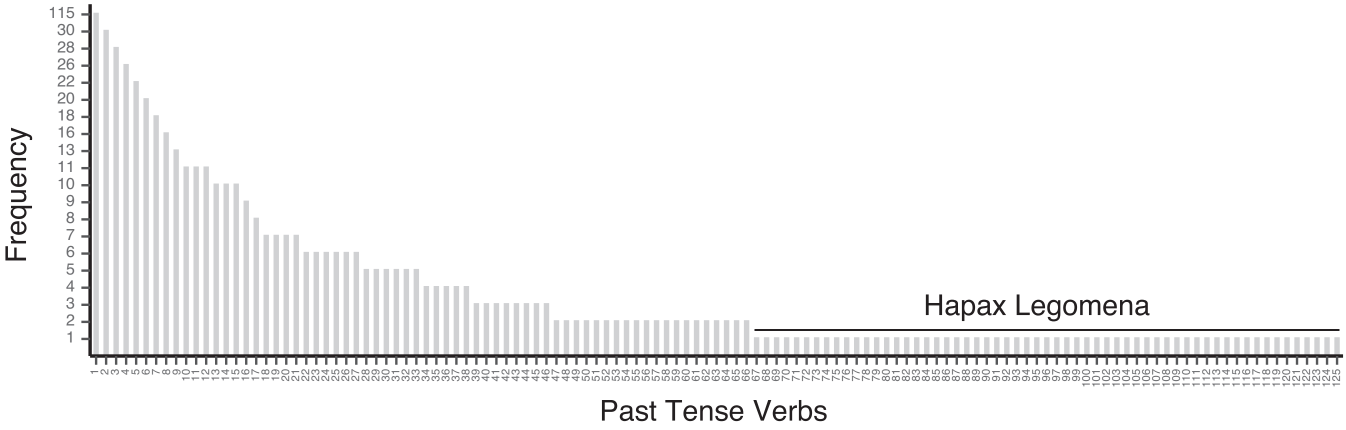

FIGURE 2 Past tense *-ed* distribution from one child in the data. The *y*-axis represents token frequency. The *x*-axis represents distinct past tense verbs that occurred with the suffix *-ed*. The black line marks the manipulation that removes hapaxes (60 in this case).

novel contexts would compromise generalization behavior. Our simulations allow us to test whether, in accordance with this prediction, reducing the number of novel verbs with *-ed* in the input would result in inferring a lower productivity for *-ed*, in turn reducing the likelihood of generalization. We then seek explanations for the observed pattern using the structural representations of the model and its impaired counterparts. Specifically, we test whether the difficulty with generalization is due to an increased reliance on preceding stem context when retrieving *-ed*.

The verb data for 17 children were extracted from the CHILDES corpus. The children were randomly selected from a pool of children whose data included fewer than 30,000 verb tokens. The reason for selecting small sample sizes was to simulate the effect of processing difficulties early in development. However, this upper limit on sample size was the only limitation we imposed on the data. As a result, verb samples came from a range, which ensured that the prediction of the model is not specific to a certain sample size and remains relevant at different stages of learning in early development. The original data were coded based on the inflectional categories of regular and irregular past-tense, 3rd person singular present-tense, and no suffix. These formed the basis of the TD model for each child's data.

We use hapax legomena—that is, words with frequency 1 in each sample—to quantify how often novel verbs with *-ed* are encountered and/or processed by children. To instantiate processing-related deficits that reflect our hypothesis, we manipulate the number of hapaxes that were the result of a stem's occurrence with *-ed* in the data for each child. Children's type count of *-ed* ranged from 38 in the smallest data sample to 130 in the largest (see Figure 3 for more details).

We created two models that instantiate our theory of DLD, which we refer to as DLD models. In the first model, henceforth *TailCut*, we simply removed hapaxes from the tail of the *-ed* distribution in each child's data. This model simulates a reduction in the number of novel *-ed* verbs addressed to the child. In the second model, henceforth *TailShift*, hapaxes in the tail of the *-ed* distribution were removed and reassigned to the bare form distribution. This was done to simulate a child's processing difficulty, resulting in processing the *-ed* hapaxes as the more familiar bare form, or a new verb. If an *-ed* hapax was the output of a novel stem with *-ed*, it was assigned a frequency of 1 in the bare form distribution. If an *-ed* hapax was the output of a familiar stem and already appeared in the corpus as a bare form, its frequency in the bare form distribution was increased by 1. Figure 2 presents example data from one child, where *-ed* hapaxes, which were removed to create the TailCut model, are marked.

A control condition was created to test the effect of removing tokens equal to the number of *-ed* hapaxes from the head of distribution where higher frequency items reside. This was done independently for each child, as the number of hapaxes differed from one dataset to another. If the highest frequency word was larger than the number of hapaxes, its frequency was reduced by the number of hapaxes in the data set. If the highest frequency item had a frequency lower than the number of hapaxes, then the frequency of each high frequency item was divided in half (rounded up for odd numbers) until the total reduced token frequency reached the count of hapaxes. The result was a condition, henceforth *FlatHead*, with the same number of tokens but different number of types from the TailCut/TailShift distribution. Because we removed items from the tail of the distribution to create the DLD models, we refer to these as the short-tail models and refer to the TD and FlatHead with more items in the tail as the heavy-tail models.

The differences in type and token count for the four conditions are summarized in Figure 3. As evident from the top left panel, *-ed* hapaxes comprise a large number of verb types in all datasets (approximately 50% on average). This difference, however, is negligible in the context of all regular verb tokens as shown in the bottom right panel.

The model was run for a total of 100 sweeps through each child's dataset with the following hyperparameter settings: $PYa = 0.5, PYb = 100, \vec{\pi} = 1, \vec{\psi} = (0.5, 0.5)$. The verbs were presented to the model one at a time. Each model was run 10 times, initiated with a new random seed each time. This resulted in 170 simulations on the full training set. To assess generalization behavior, we presented each model with a WUG test, where a novel stem that has not been observed in the input, (WUG) was generated by the model with *-ed* (see O'Donnell, 2015, for

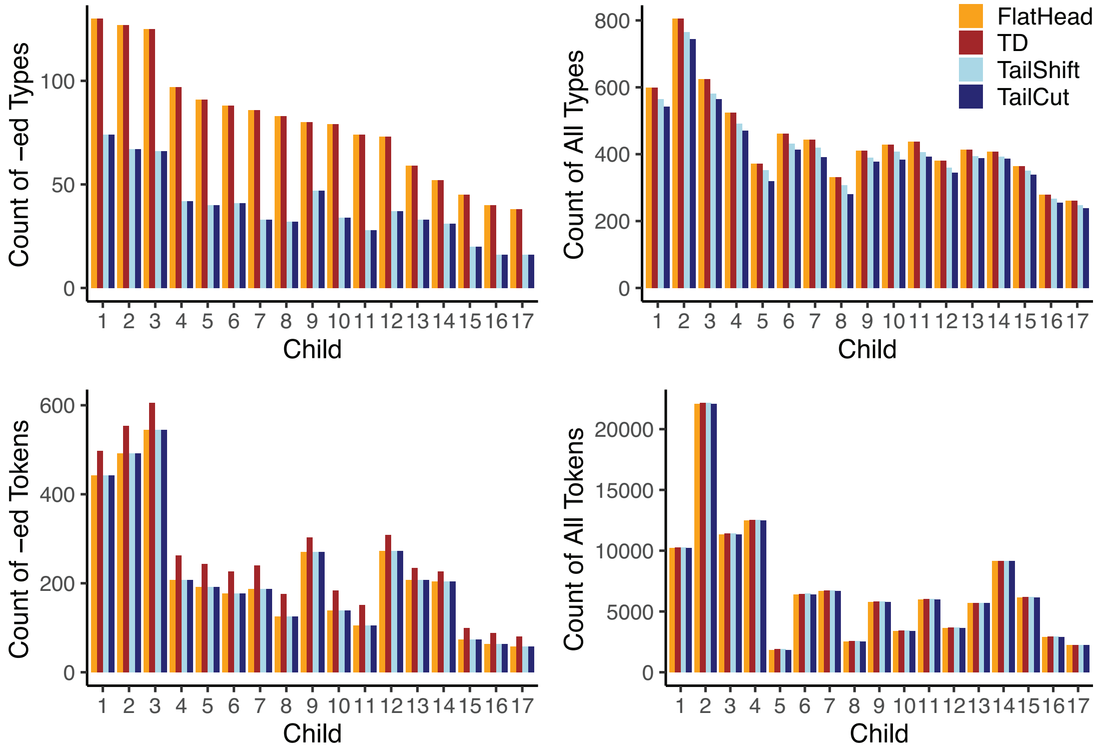

FIGURE 3 Differences in types and token counts in the four conditions of FlatHead, TD, TailShift, and TailCut for each child. The two top panels are counts of type frequency and the two bottom panels are counts of token frequency. The top left panel presents the number of types for *-ed*. The top right panel presents the number of types of all inflected verbs. The bottom left panel presents the count of tokens for *-ed*. The bottom right panel presents the count of all verb tokens in the data. While *-ed* hapax legomena represent approximately 50% of the *-ed* types on average, they represent a very small percentage of all inflected verb tokens. This suggests that when only token frequencies are taken into account, the difference between TD and DLD inputs is negligible.

a detailed description of how the wug test is implemented in Fragment Grammars).

4.1 | Results and discussion

To compare DLD and TD models' performance on the generalization task in the WUG test, we measured the production probability of WUG with *-ed* (WUGGED). We used inside score—the probability under the grammar that the nonterminal V consists of a specific set of terminals, *wug* and -ed—to quantify production probability. All statistical analyses were conducted in R version 4.0.2 (R Core Team, 2020).

Figure 4 presents differences between models in their probability of generalizing the *-ed* suffix to a novel stem, or production probability of WUGGED. The data were analyzed using a linear mixed effect regression model with production probability of WUGGED as the dependent variable and Condition as the independent variable. Random intercept for Child was included in the model. Relative to TD, that is, the model with full data, both TailCut and TailShift assigned a significantly lower production probability to WUGGED ($\hat{\beta} = -0.49, t = -35.33, p < 0.0001$ for TailCut; $\hat{\beta} = -0.52, t = -37.74, p < 0.0001$ for TailShift). As predicted, TD and FlatHead were not significantly different from each other ($\beta = 0.0007, t = -0.05, p = 0.96$), but FlatHead was different from both TailCut ($\hat{\beta} = -0.49, t = -35.28, p < 0.0001$) and TailShift ($\hat{\beta} = -0.52, t = -37.69, p < 0.0001$).

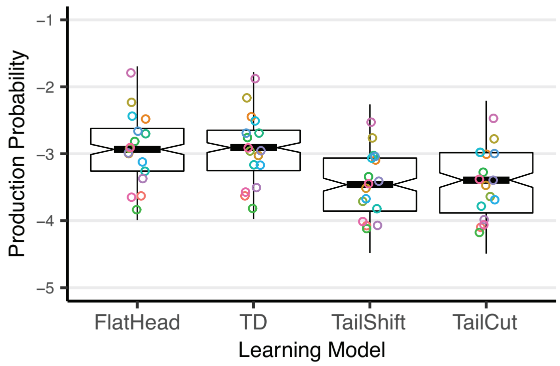

FIGURE 4 Probability of generalizing the *-ed* inflection to a novel context in the four models. The *x*-axis represents the learning models. The *y*-axis is the production probability (inside score) of WUGGED. Each color represents data from a different child. Each small circle represents the mean of the 10 runs of the model for a child. DLD models (TailShift and TailCut) assign a lower probability to *-ed* in novel contexts compared to their TD counterparts (FlatHead and TD).

These results suggest that, as predicted, a reduction in the number of past-tense hapax legomena in the input of the DLD models

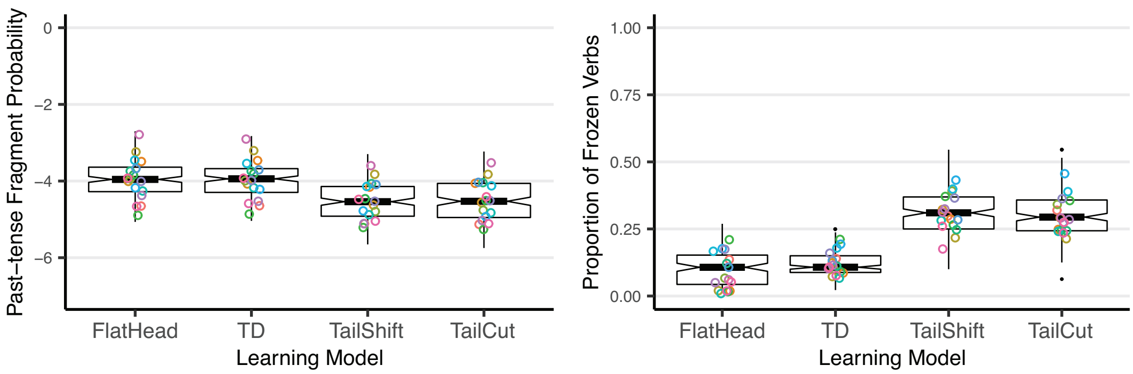

FIGURE 5 Left panel: The probability of the past-tense fragment in the grammars across the four conditions. Right panel: the proportion of frozen verbs in the learned grammar to the number of verb types in the input for each model. Each color represents data from a different child. Each circle represents the mean of 10 runs of the model for a child. There is a trade-off between the past-tense fragment and frozen verbs. The short-tail DLD models assign lower probability to the past-tense fragment as they create more frozen verbs.

negatively affected their generalization behavior. The results provide support for the link between experiencing a form in novel contexts and generalization, as proposed by the Competition–Compensation Account: problems with generalizing a suffix could be attributed to difficulty of children with DLD to detect that suffix in novel contexts.

To better understand why the short-tail DLD models do not perform as well as the two heavy-tail models on the generalization tasks, we examined, for each grammar associated with each model, the partitioning or distribution of the verb fragments—that is, tree fragments with nonterminal V at the root (see Figure 1). We first examined the two fragments that preserve the inflection nonterminal: the full computation fragment (V → STEM INFLECTION, Figure 1a) and the fragment in Figure 1c (V → … INFLECTION). In the grammars across the four conditions, we found no difference in the probability of the full computation fragment and no difference in the number of verbs generated with fragment c.

We then examined the past-tense fragment (V → STEM *-ed*, Figure 1b) and frozen fragments as in V → *dance -ed* (Figure 1d) in each grammar. In comparison to the past-tense fragment, which corresponds to retrieving a context-independent *-ed*, the frozen fragment in Figure 1d corresponds to context-dependent activation of the *-ed*.

Figure 5 presents the differences in the probabilities of the past-tense fragments and the number of frozen verbs—verbs that are stored as one chunk with *-ed*—in the grammars across the three conditions. As evident from the left panel, the past-tense fragment has a lower probability in the short-tail DLD grammars (TailShift and TailCut) relative to the two heavy-tail TD models (FlatHead and TD). Mixed effect models with the probability of past-tense fragment as the dependent variable and Condition as the predictor, with random intercept for Child confirm this. While neither TD and FlatHead ($\hat{\beta} = 0.009, t = 0.6, p = 0.552$) nor TailCut and TailShift ($\hat{\beta} = -0.02, t = -0.93, p = 0.353$) are different from each other, the past-tense fragment has a higher probability in TD relative to both TailCut ($\hat{\beta} = -0.55, t = -34.62, p < 0.0001$) and TailShift ($\hat{\beta} = -0.56, t = -35.55, p < 0.0001$) as well as a higher probability in FlatHead relative to both TailCut ($\hat{\beta} = -0.56, t = -35.21, p < 0.0001$) and TailShift ($\hat{\beta} = -0.57, t = -36.14, p < 0.0001$).

At the same time, more frozen verbs are formed in the short-tail models. The right panel of Figure 5 shows that the short-tail models have a higher number of frozen verbs relative to the heavy-tail models. Mixed effect models with proportion of frozen verbs to all verb types as the dependent variable and Condition as the predictor, with random intercept for Child confirm a significant difference between the TailCut ($\hat{\beta} = 0.18, t = 31.78, p < 0.0001$) and the TailShift ($\hat{\beta} = 0.19, t = 35.56, p < 0.0001$) models relative to TD, and TailCut ($\hat{\beta} = 0.2, t = 33.58, p < 0.0001$) and TailShift ($\hat{\beta} = 0.21, t = 35.22, p < 0.0001$) models relative to FlatHead. FlatHead and TD were also different from each other ($\hat{\beta} = -0.03, t = -4.27, p < 0.0001$) as fewer models in the FlatHead conditions created frozen verbs due to a reduced number of frequencies in the head of the *-ed* distributions—only 132 models in the FlatHead condition created frozen verbs relative to all other conditions where all the 170 models created some number of frozen verbs.

These results suggest that a tendency to freeze more verbs and its effect on the probability of the past-tense fragment may be behind lowering the productivity of *-ed* in the DLD models. Looking at the maximum a posteriori tree (MAP tree) for the novel verb WUGGED, we see that 169 out of 170 models that were run, primarily used the past-tense fragment in creating WUGGED. Thus, reducing the probability of the past-tense fragment leads to a lower production probability for *-ed* in the context of novel verbs in the short-tail models.

Why were more items frozen in the DLD conditions? The input to the short-tail models had fewer verb types with *-ed*, as it lacked *-ed* hapax legomena. Consequently, the short-tail distributions had, on average, an overall higher frequency with *-ed* compared to the heavy-tail distributions ($\text{Mean}_{\text{TailShift\&TailCut}} = 5.73$ vs. $\text{Mean}_{\text{FlatHead}} = 2.75$ vs. $\text{Mean}_{\text{TD}} = 3.28$). A higher relative frequency with a suffix translates to more opportunities to chunk verbs with that suffix (Hay, 2001), which trades off against a context-independent representation of *-ed*.

To substantiate the claim that frozen forms with *-ed* are the result of high relative frequency of stems with *-ed*, we examined the frequency of occurrence of frozen and nonfrozen verbs with *-ed*. For each stem, we calculated its frequency of occurrence with the *-ed*

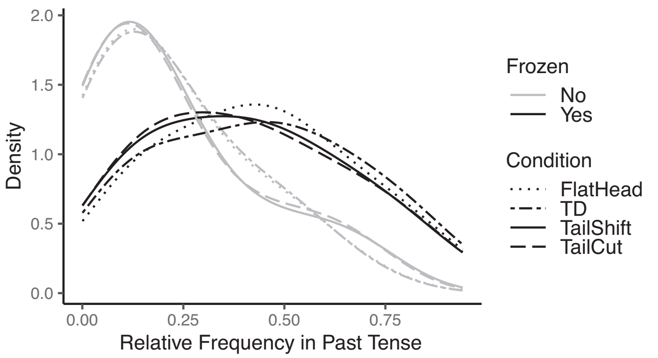

FIGURE 6 The relative frequency of frozen and nonfrozen verbs in the four conditions. The black lines represent verbs that were frozen, that is, stored with the preceding stem context, in the grammar of the models while the gray lines represent verbs that did not freeze with *-ed*. Dotted lines represent FlatHead, dot-dashed lines represent TD, solid lines represent TailShift, and dashed lines represent TailCut conditions. The relative frequency of verbs frozen in the past tense in the grammar of the models in all conditions was higher than the relative frequency of verbs that were not frozen.

relative to all suffixes, $\frac{N(\text{STEM}+-ed)}{N(\text{STEM})}$. Figure 6 shows that the relative frequency of verbs frozen in the past tense in the grammar of the models in all conditions was higher than the relative frequency of verbs that were not frozen. The results of a logistic regression model with the binary variable of frozen-ness as the dependent variable and relative frequency as the predictor suggests that this is a reliable effect. We found a significant main effect of relative frequency ($\hat{\beta} = 3.84$, $z = 19.83$, $p < 0.0001$) and a nonsignificant interaction with condition (all $ps > 0.1$, *n.s.*), indicating that in all conditions, higher relative frequency of a stem with *-ed* resulted in chunking the two as a frozen verb fragment.

Relative frequency of occurrence with a suffix, then, can predict the likelihood of generating frozen fragments with that suffix. Note that, as shown earlier, a tendency to freeze more verbs with *-ed* in the DLD models as a result of reducing novel occurrences with *-ed* contributes to lowering the probability of the past-tense fragment.

4.2 | Compensation

The compensation component of the Competition–Compensation Account predicts that when the child experiences strong competition in accessing the inflected form, she chooses a competing alternative that is highly accessible. We examined this prediction by comparing the probability that the bare stem relative to another potential alternative, the suffix *-s*, replaces *-ed*. Consistent with the predictions of the compensation component, for all four models in our simulations, bare stem is approximately 10 times more likely than *-s* in novel generalization tasks (WUG relative to WUGS). This is an underestimate: the effect is predicted to be stronger if problems with detecting novel instances of *-s* suffix were also reflected in the data of the DLD models in the same manner as *-ed*.

The advantage for bare stem is, of course, due to its high frequency (Bybee, 1985; Räsänen et al., 2014). Harmon and Kapatsinski (2017) have demonstrated that high frequency of a form results in the extension of that form to related contexts through its effect on accessibility. Further evidence for the effect of accessibility on children's compensatory choices comes from studies that analyzed differences between verbs in English. These studies have demonstrated that in the speech of both TD children (Räsänen et al., 2014) and children with DLD (Kueser et al., 2018), verbs that are more likely to appear in bare form in the input are the verbs whose bare forms are more likely to be overextended to substitute for inflected forms. As Harmon and Kapatsinski (2017) argue, an accessibility-driven choice in production is especially likely when the speaker is facing planning difficulty during production. In line with this claim, the Competition–Compensation Account proposes that speakers who are more likely to experience competition during planning—such as children with DLD—are also more likely to exhibit compensation.

Finally, note that the Competition–Compensation Account does not rule out the possibility that the compensatory form is a form other than the bare stem. However, our account predicts any other substitutions to be unlikely in English. Of course these substitutions are conditioned or influenced by context-specific semantic and phonological factors. In fact, there is evidence that forms such as *-s* suffix are sometimes produced over the more frequent bare stem (see, Krok & Leonard, 2015, for a review). However, lower frequency of bare stem in languages where *-s* extension has been reported compared to English, or, as pointed out by Krok & Leonard (2015, p. 1338), priming during a prompt in English may have contributed to increasing the accessibility of other competing suffixes such as *-s*, resulting in their production over the bare form. Predicting such influences as well as semantic and phonological effects is an interesting question to pursue in future research, and would require building a model that encodes sufficiently detailed semantic and phonological information about the context.

Overall, the results of Simulation I provided support for the predictions of the Competition–Compensation Account: Performance on the generalization test indicated that difficulty processing a form in novel contexts in the short-tail DLD models compromised generalization of *-ed* to novel contexts. Examining the models' structural representations revealed that poorer performance on the generalization tasks in the DLD models is attributed to their higher reliance on context-dependent activation of *-ed*. Whereas opportunities to experience *-ed* in novel contexts in the TD models lead to strengthening the context-independent representation of *-ed*, DLD models with fewer novel contexts were more likely to store *-ed*. Using the same generalization test, we further demonstrated that the bare form has an advantage over other suffixes during compensation.

The prevalence of frozen forms in the grammars learned by DLD models raises a question regarding the long-term effects of such learning. There is considerable evidence that children make higher level inferences on the basis of what they have learned about language. For example, children who learn many shape-based categories develop a bias to interpret subsequent labels as being defined by shape (as opposed to color, material, and so on) (e.g., Colunga & Smith, 2005;

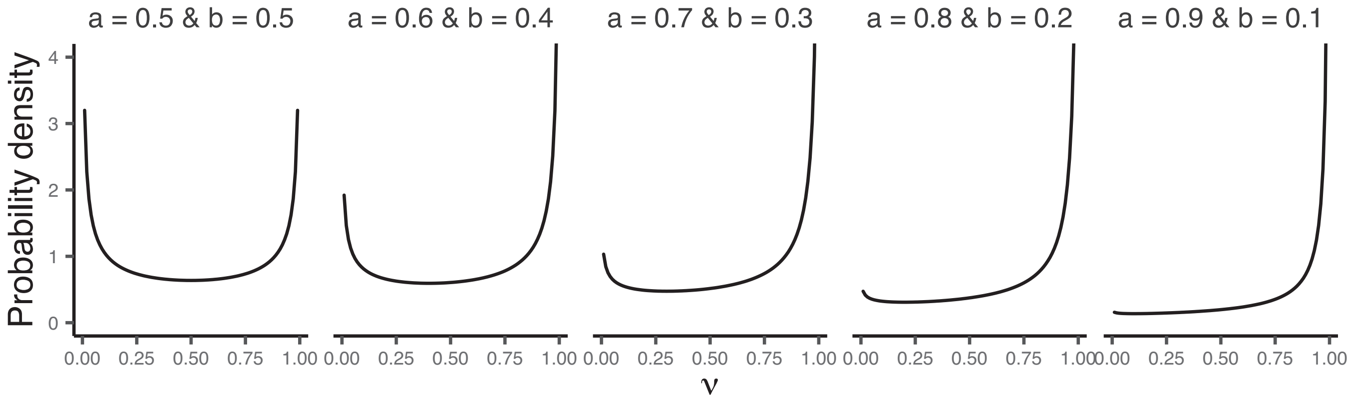

FIGURE 7 Beta distribution parameter used in the model to bias computation versus storage using parameter ν. The leftmost panel shows a Beta distribution with an unbiased $\vec{\psi} = (a, b)$ set at $\vec{\psi} = (0.5, 0.5)$—the parameter settings of Simulation I. The bias increases with a change in the shape parameters, a and b as we move to the right panels. Sampling ν from the distributions in the second through fifth panels encourages storage of a form with its co-occurring contexts in the model.

Kemp et al., 2007; Smith et al., 2002). Analogously, children who learn many frozen forms may develop a bias to interpret subsequent verbs they hear as frozen forms, and the bias could in turn impact subsequent stages of learning. We explore the potential implications of such learning biases in Simulation II.

5 | SIMULATION II

Simulation II investigates a possible link between the effect of processing limitations, which lead learners to perceive short-tail distributions, and a learned bias to over-rely on stored representations. The theoretical basis for investigating this link is the hypothesis that having interpreted much of their input as frozen forms in the past may lead children to develop a bias toward storing frozen forms. We show that such a bias could affect children's subsequent inferences, leading to larger effects than would be predicted on the basis of the processing limitations alone.

Fragment Grammars assume that there is a parameter, ν, that controls the model's decisions at each nonterminal (V, STEM, and INFLECTION) to halt or continue the expansion of the right-hand side of a rule. This parameter controls the opportunity for the storage of a frozen form, with high values of ν favoring storage. Leaning towards storage in the model corresponds to lower opportunities to store partial fragment such as V → STEM *-ed* and more opportunities to store fragments as unanalyzed chunks such as V → *danced*. The prior distribution on ν in the model is a Beta distribution parameterized by $\vec{\psi}$,

$$\vec{\nu} \sim Beta(\vec{\psi}). \tag{2}$$

The leftmost panel of Figure 7 illustrates this prior distribution with a parameter value of $\vec{\psi} = (0.5, 0.5)$, which encodes a symmetric prior distribution over ν without any particular bias toward storage. As we move to the right of the graph, the first number, a, increases and the second number, b, decreases until $\vec{\psi} = (0.9, 0.1)$. This corresponds to an increasing bias toward storing frozen forms.

In Fragment Grammars, the parameter of the prior distribution, $\vec{\psi}$, is fixed and does not change during learning. This contrasts with previous language learning models that have hypothesized that children update these types of higher level beliefs during learning (Kemp et al., 2007; Perfors et al., 2010). Deriving an analogous model to Fragment Grammars that updates its beliefs about $\vec{\psi}$ is mathematically challenging, so we instead approximate the effect of such learned biases by manually setting $\vec{\psi}$ to a value that favors storage over computation. Simulation II asked what effect this parameter manipulation has on the model's learned grammar and its resulting generalization behavior.

5.1 | Results and discussion

Changes in the $\vec{\psi}$ parameter resulted in two changes in the grammars, in line with our prediction. First, there was an overall increase in the number of verbs that were frozen. However, this was most prominent for the short-tail DLD models (left panel of Figure 8). We ran a mixed-effect regression model with the count of frozen verbs as the dependent variable and Condition and storage bias ($\vec{\psi}$ parameter) and the interaction between the two as fixed effects. Random intercepts for Child and random slopes for parameter within Child were included in the model. The results of model comparison with a model that only included the main effects of Condition and parameter indicated a significant interaction between Condition and $\vec{\psi}$, ($\chi^2(3) = 410.85, p < 0.0001$). The effect of $\vec{\psi}$ on the number of frozen verbs was significantly greater in TailCut and TailShift compared to TD ($\hat{\beta} = 2.06, t = 14.95, p < 0.0001$ for TailCut; $\hat{\beta} = 1.87, t = 7.29, p < 0.0001$ for TailShift). FlatHead was not significantly different from TD ($\hat{\beta} = -0.15, t = -1.01, p = 0.314$). These results suggest that a change in $\vec{\psi}$ drives the models to create a larger number of frozen forms, but that this effect is larger in the two DLD models.

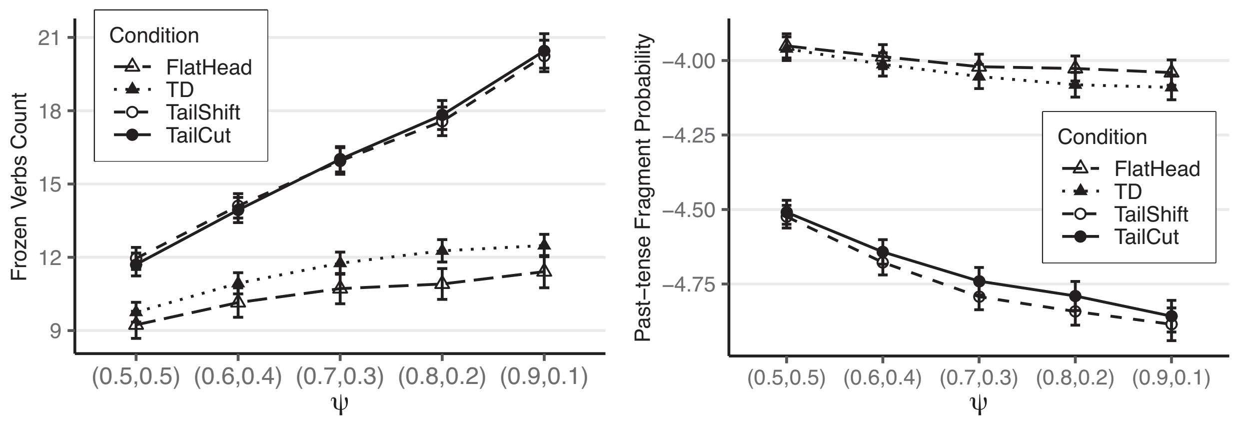

FIGURE 8 Change in the number of frozen fragments (left panel) and the log probability of the past-tense fragment (right panel) as a function of changing $\vec{\psi}$ that stands for a storage bias. Change in $\vec{\psi}$ from (0.5,0.5) to (0.9,0.1) drives the models to rely more on storing *-ed* with the preceding context (co-occurring stems). Long-dash and dotted lines represent the FlatHead and TD models, respectively. Dashed and solid lines represent the TailShift and TailCut models, respectively. Overall, increasing the storage bias leads to the creation of more frozen forms and a reduction in the past-tense fragment probability with a greater effect on the short-tail DLD models, TailShift and TailCut.

Second, the past-tense fragment (right-hand side of Figure 8) in the grammar of all four conditions had lower probability, but this was especially the case for the DLD models. We analyzed the data using a mixed-effect regression model with the probability of past-tense fragment as the dependent variable and Condition and $\vec{\psi}$ parameter and the interaction between the two as the fixed effects. Random intercepts for Child and random slopes for parameter within Child were included in the model. The results of model comparison with a model that only included the main effects of Condition and parameter indicated a significant interaction between Condition and $\vec{\psi}$, ($\chi^2(3) = 383.43, p < 0.0001$). The effect of $\vec{\psi}$ on lowering the probability of the past-tense fragment was significantly greater in TailCut and TailShift compared to TD ($\hat{\beta} = -0.09, t = -12.79, p < 0.0001$ for TailCut; $\hat{\beta} = -0.1, t = -13.45, p < 0.0001$ for TailShift). The effect of $\vec{\psi}$ was significantly weaker in FlatHead when compared to TD ($\hat{\beta} = 0.015, t = 2.184, p = 0.029$). Thus, a change in the $\vec{\psi}$ parameter drives the models to lower the probability of the past-tense fragment, but significantly more in the two DLD models.

The results confirm our hypothesis that many of the verbs that under unbiased conditions (Simulation I) were generated with the past-tense fragment, and therefore contributed to this context-independent fragment's probability, are now produced as frozen chunks. Importantly, the change in the number of frozen forms was particularly high in the short-tail DLD conditions, suggesting that a bias to process forms as one unit with their preceding context has a stronger effect when it is combined with difficulty processing a form in novel contexts.

To investigate the effect of storage bias on the models' generalization behavior, we presented each model with a WUG test and measured the production probability of WUGGED. The results are presented in Figure 9. The short tail models have a large drop in the probability of WUGGED as a function of increase in $\vec{\psi}$.

To assess whether the effect of over-reliance on storage differs across the four conditions, we ran a mixed-effect regression model with the production probability of *-ed* in a novel context (WUGGED) as the dependent variable and Condition and $\vec{\psi}$ parameter and the interaction between the two as the fixed effects. Random intercepts for Child and random slopes for parameter within Child were included in the model. The results of model comparison with a model that only included the main effects of Condition and parameter indicated a significant interaction between Condition and $\vec{\psi}$, ($\chi^2(3) = 414.88, p < 0.0001$). The effect of $\vec{\psi}$ on the production probability of *-ed* in a novel context was significantly greater in TailCut and TailShift compared to

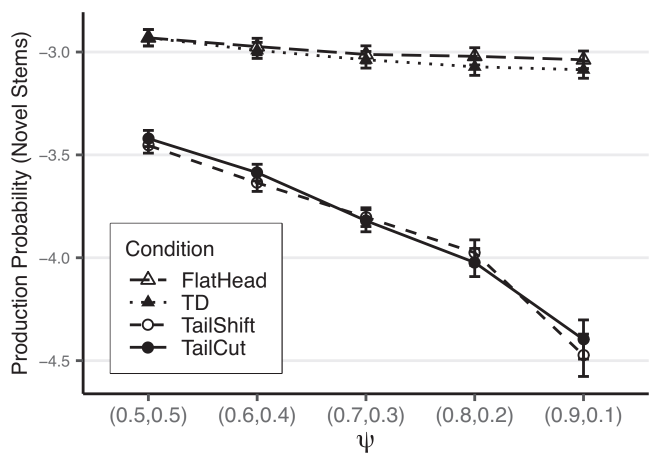

FIGURE 9 Change in the production probability of *-ed* with a novel form in the four conditions as a function of change in the $\vec{\psi}$ parameter that stands for a storage bias. The *x*-axis shows change in the $\vec{\psi}$ parameter. Change in $\vec{\psi}$ from (0.5,0.5) to (0.9,0.1) drives the models to rely more on storing *-ed* with the preceding contexts, that is, co-occurring stems. The *y*-axis shows the log probability of WUGGED. Longdash and dotted lines represent the FlatHead and TD models, respectively. Dashed and solid lines represent the TailShift and TailCut models, respectively. Overall, increasing the storage bias leads to lowering the probability of generalizing -ed in the four conditions, with a significantly stronger cost for the two DLD models, TailShift and TailCut.

TD ($\hat{\beta} = -0.28, t = -14.4, p < 0.0001$ for TailCut; $\hat{\beta} = -0.28, t = -14.31, p < 0.0001$ for TailShift). FlatHead was not significantly different from TD ($\hat{\beta} = 0.02, t = 0.94, p = 0.346$). Therefore, the effect of storage bias on generalizing *-ed* in the four conditions differed, with a stronger cost for the DLD models.

Previous literature has suggested that children update their higher level biases during language learning (Kemp et al., 2007; Perfors et al., 2010). In this case, such updating would lead learners to develop a bias to over-rely on a context-dependent representation of *-ed*—parse and store *-ed* with stems that have frequently preceded it. The findings of Simulation II indicate that this storage bias would further impede their generalization of the *-ed* inflection in novel contexts. Crucially, the impairment in generalization was significantly stronger for models that have experienced *-ed* in fewer novel contexts, (the DLD models). This raises the possibility that an initial processing difficulty could have far-reaching effects on generalization, even beyond those captured in Simulation I, if it impacts children's inferences about their grammar at multiple levels of abstraction.

6 | GENERAL DISCUSSION

The present work introduces the Competition–Compensation Account of Developmental Language Disorder (DLD), proposing that processing difficulties of children with DLD have a disproportionate effect on processing novel inflected forms. As a result, children with DLD have to overcome a stronger competition when retrieving inflections in unfamiliar contexts. Using computational modeling, we demonstrated that generalization difficulties in the DLD models that did not have novel forms with *-ed* in their input was due to a weaker context-independent representation of *-ed* as shown by a lower probability of the past-tense fragment (V → STEM *-ed*; Figure 1b). These models instead created more frozen verbs, which amounted to a context-dependent activation of *-ed* and contributed to lowering reliance on the context-independent *-ed* representation. We have argued that easy retrieval of the context-independent representation, which is facilitated by experiencing *-ed* in novel contexts is crucial for reliably accessing *-ed* during sequential planning following unfamiliar contexts.

A weaker context-independent representation of *-ed* could explain why curbing over-extension of competing responses with higher frequency, such as the bare form, may be more difficult for children with DLD. We characterized the over-extension of bare form to *-ed* contexts as a type of compensation, and demonstrated that the production of bare form was favored over other potential candidates such as the 3rd person present-tense *-s* in generalization tests. Using an experimental paradigm that involved manipulating the accessibility of a form while keeping its frequency constant, Harmon and Kapatsinski (2017) demonstrated that when high frequency results in increase in accessibility of a form, speakers extend that form, as opposed to its competitor, to novel semantically related contexts (see also Harmon, 2019; Kapatsinski, 2018; Koranda et al., 2021; Kapatsinski, 2022). The high accessibility of the bare form, coupled with its semantic and form-based similarity to its inflected past-tense form due to stem overlap, leads to its repeated extension to past-tense contexts, resulting in inconsistent inflectional marking (see also, Hoeffner & McClelland, 1993). In addition, bare-form production is ideal from a communicative perspective for a speaker with planning or retrieval difficulty. It is not only easier to plan and execute (Oldfield & Wingfield, 1965), but it also minimizes both form- and meaning-related miscommunications, aiding the speaker in reducing planning difficulty while still getting the bulk of the meaning across to the listener, and is observed in the language of both TD children and children with DLD (Thordardottir & Ellis Weismer, 2001). All English-speaking children go through a stage where they fail to curb the extension of bare stem to other contexts. Yet, for children with DLD, lower production probability for the past-tense fragment means overcoming stronger competition.

We used the model's parameters to explore the possibility that limited experience with novel inflected verbs lead to a storage bias that influenced processing of the inflection above and beyond the effect of difficulties with processing novel forms. Following the introduction of a storage bias, where *-ed* was more likely to be retrieved using the preceding stem contexts, generalization in the TD models remained more or less stable, while the same bias in the DLD models exaggerated difficulties with generalization.

The interaction between storage bias and processing difficulties and their effect on generalization helps make sense of the variability in generalization behavior in the DLD population. Children with DLD are a heterogeneous group and are not only variable in generalization behavior, but also in how effectively they respond to interventions (Law et al., 2004; Rinaldi et al., 2021). Children whose processing is influenced by a stronger bias for storage may not benefit as much from exposure to data in the interventions. Our findings suggest that variability in morphological deficits may be predictable from individual differences in the degree to which children rely on alternative solutions when they have difficulty retrieving a form in a novel context. If this is true, studying compensatory behaviors should be at the heart of studying morphological deficits in DLD.

We have argued—in accordance with accessibility-driven language production—that compensatory choices are very often highly accessible forms with semantic overlap with the target form. To continue to communicate under production-related pressures, children with DLD may rely on whatever form is most accessible, which is very often the bare form. This is a compensatory behavior with the goal of communicating a meaning as close as possible to the intended meaning. In fact, Harmon and Kapatsinski (2017) show that semantically similar over-extensions appear even when the speakers are generally aware that there is a more appropriate alternative to the form they just produced. The production pressures and the resulting compensatory behavior may result in comprehension–production dissociation in mapping forms to meanings (Gershkoff-Stowe & Smith, 1997; Kapatsinski & Harmon, 2017; Leonard & Dispaldro, 2013; Naigles & Gelman, 1995, see also Barak et al., in revision, for computational modeling of this phenomenon). In this way, accessibility-driven compensation explains defaulting to high-frequency forms that has been shown to be influential in accounting for cross-linguistic differences in morphosyntactic problems observed in children with DLD (e.g., Freudenthal et al., 2021a, 2021b).

Further support for the contribution of semantic relatedness to over-extension of bare form comes from the observation that children with DLD over-rely on a small group of high-frequency verbs, also known as general, all-purpose (GAP) verbs or light verbs (e.g., *do*, *make*, *put*) in their production. For example, children with DLD may over-extend the verb *make* to a context such as *I have to make names* where TD children would use a more specific verb such as *write* (Rice & Bode, 1993). Over-extensions of GAP verbs to contexts where a semantically more specific verb is more appropriate point to the contribution of meaning independently of form. GAP verbs are highly accessible due to their high frequency, and can help partially communicate the meaning when a better form is inaccessible. However, the choice of the compensatory form may be the result of competition at different stages of planning. As Rice and Bode (1993) point out GAP verbs may be overextended to the context of other verbs when the child is experiencing stem retrieval difficulties.

Finally, cross-linguistic evidence from languages with richer morphological paradigms provides more nuanced test of accessibility-driven compensation. For example, in Italian, it is the 1 st person singular form and not the higher frequency 3 rd person singular form that regularly replaces the 1 st person plural (e.g., Bortolini et al., 1997), revealing sensitivity of the compensatory form to semantic overlap between competing forms, where the most accessible form given the shared semantic cue of 1 st person compensates for the inaccessible target form. We have not modeled the contribution of semantics to the choice of the compensatory form in the present paper, but we believe that over-extension of the bare form to past-tense contexts is also influenced by semantic overlap between the two.

A central idea within the Competition–Compensation Account is that novel applications of inflectional suffixes are more vulnerable to the processing difficulties of children with DLD. Although our simulations do not address the exact mechanism behind this proposal, work on fast-mapping, nonword repetition, and word recognition abilities of children with DLD provides some support for this argument. Alt (2011) found an interaction between performance and word length: while children with DLD learned shorter words similarly to their TD peers, they had difficulty with learning longer words (Alt, 2011; Alt & Suddarth, 2012). Gathercole (2006) and colleagues found that children with DLD are as accurate as their TD peers when repeating short nonwords, but are much less accurate than peers when repeating long nonwords (see also Edwards & Lahey, 1998; Gathercole & Baddeley, 1990; Graf Estes et al., 2007), suggesting difficulty with unfamiliar phonological sequences. A more pertinent finding is the finding of Maillart et al. (2004) who found that detecting slight differences at the end of words was particularly difficult for children with DLD.

These findings predict that children with DLD would have more difficulty recognizing hapaxes, because hapaxes either include phonologically unfamiliar sounds, or when they do have a familiar stem, their recognition requires discriminating the novel inflected word from familiar bare stems using a nonsalient form appearing at the end of the word. In fact, studies of word recognition using the visual world paradigm suggests that when there is slight overlap between competing candidates, children with DLD do not cope with ambiguity as well as their TD peers, showing less fixations to the target form and failing to inhibit competing forms (McMurray et al., 2010, 2019, 2022). Inhibiting morphologically related competitors may pose an even greater challenge to children with DLD due to extensive form and meaning overlap between competing candidates. Nevertheless, the Competition–Compensation Account remains open to the idea that there may be several sources of processing-related difficulties that affect learning morphosyntactic information, but it does predict that these difficulties are relatively exacerbated on encounters in novel contexts.

6.1 | Relationship to other accounts of DLD

The Competition–Compensation Account differs from other processing-based accounts in that it assumes a stronger effect of processing difficulties on novel and unfamiliar instances. Most processing-based accounts would either predict that a failure to process an instance of a morpheme may happen with equal probability at high or low frequencies or do not address the possibility of an interaction between processing difficulties and experience. The Competition–Compensation Account, however, predicts a sharp decline in failure to register an instance of a form with increasing token frequency, which may explain better performance on high frequency regular verbs (Van der Lely & Ullman, 2001). At the same time, this account predicts an adversarial effect of high frequency of repeated occurrence in identical contexts (see also Bybee & Brewer, 1980; O'Donnell, 2015; Stemberger & MacWhinney, 1986). If what the child experiences is limited to a small number of stems with high token frequency with *-ed*, production of *-ed* will become reliant on these stems, and an independent representation of the suffix will be weak.

The Competition–Compensation Account is in agreement with the Procedural Deficit Hypothesis in that morphosyntactic and sequential planning difficulties of children with DLD should be conceptualized as problems with procedural learning (see also, Hsu & Bishop, 2010). However, it argues that successful sequential planning of a form in various contexts requires the activation of that form independently of the preceding contexts and that experiencing a form in novel contexts strengthens the context-independent activation of that form. Since parsing a novel inflected form at least in some cases requires detecting that the inflected form is a new version of a familiar stem, and since this type of novelty detection is a function of the declarative memory and not procedural memory (Kafkas & Montaldi, 2018; Kumaran & Maguire, 2007; Ullman, 2016), we have touched on the possibility that problems with sequential planning originate in the declarative memory system, or that the distinction between these two systems may not contribute to understanding DLD (see, e.g., Goffman & Gerken, 2020; McCauley, 2020, for a discussion). Future work on recognition abilities of children with DLD, especially the ability to detect forms in novel contexts could shed light on this proposal.

In accordance with the role of type frequency in productivity and the critical mass hypothesis (Marchman & Bates, 1994), SLI critical mass hypothesis (Conti-Ramsden & Windfuhr, 2002) claims that children with DLD require a larger number of types to successfully learn and generalize a morphosyntactic pattern. An increase in the number of types in the verb lexicon of children predicts the onset of past-tense overregularization errors (Marchman & Bates, 1994), and increasing the type frequency of a morphosyntactic pattern aids infants in learning that pattern in experimental settings (e.g., Gomez, 2002). Furthermore, Rispens and De Bree (2014) show that increase in type frequency helps both TD and children with DLD to extend *-ed* to novel contexts. The Competition–Compensation Account further highlights the role played by hapax legomena or novel encounters with an inflection, namely, that they increase opportunities for a suffix to be learned independently of preceding stem contexts. Our modeling work demonstrates how experiencing a form in novel contexts aids in retrieving this representation.

6.2 | Implications for testing and intervention

Our account predicts that factors that increase the recognition and use of the inflectional suffixes in novel contexts should contribute to better learning of these suffixes. Conventional treatment for inflectional morphology in children with DLD uses high frequency verbs as targets, on the assumption that it will be easier to add a morpheme to a familiar verb (e.g., Weiler, 2013). Our modeling work suggests that this may not be the best course of action if these high frequency forms have been regularly occurring with the target inflection (see also Owen Van Horne et al., 2018, 2017). We have demonstrated that experiencing a form in novel contexts makes the most influential contribution to strengthening context-independent planning of a form. Accordingly, our account suggests that treatment for verb morphology deficits will be more effective if hapaxes (and many of them) are chosen as targets. This would involve presenting a suffix with a large number of stems that are unlikely to have been heard with that suffix by the child.

Some support for the Competition–Compensation Account comes from intervention efforts by Plante et al. (2014) who demonstrated that an increase in contextual variability (type frequency) of a morpheme in the input of children with DLD lead to better performance on generalization and spontaneous use of the treated morpheme by those children (Plante et al., 2014). At the same time, because children with DLD are likely to have difficulty with detecting the inflection in novel inflected forms, it may be particularly important to facilitate recognition of the nonsalient inflection. Recognition difficulties may explain why other attempts to test the effect of presenting a suffix with varying stems have not been as successful. At least one study that tried form bombardment in variable contexts for intervention did not find improvement in learning (Plante et al., 2018). This may have been due to the fact that the study targeted contextual variability at the morphological level and syntactic level simultaneously, making every sentence unique (e.g., "Joe tripped." "The boys raced." "That girl scared him."; Plante et al., 2018, p. 325). It is possible that changing several words in the input may have burdened children by dividing their attention to more than one word, taking attention away from the pattern of consistency in the stimuli, namely, the inflection.

Finally, the Competition–Compensation Account puts forth a potential explanation for why the diagnostic accuracy of tense/agreement morphemes as a marker of DLD declines during school age (Moyle et al., 2011). As children's exposure to forms in novel contexts increases, their estimate of an inflection's productivity increases. At the same time, individual differences in processing-related difficulties and individual differences in the tendency to over-rely on context-dependent activation of a form may interact with input exposure, predicting not only differences in the severity of the deficit, but also different levels of improvement during school years.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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