ASHA American Speech-Language-Hearing Association

JSLHR

Research Note

Are Late Talkers Just Late? Neighborhood Density and Word Frequency Properties of Late Talkers' Spoken Vocabularies

Elizabeth Schoen Simmons[a] and **Rhea Paul**[a]

[a] Department of Communication Disorders, Sacred Heart University, Fairfield, CT

ARTICLE INFO

Article History:
Received December 12, 2023
Revision received June 10, 2024
Accepted July 10, 2024

Editor-in-Chief: Julie A. Washington
Editor: Raúl Rojas

https://doi.org/10.1044/2024_JSLHR-23-00769

ABSTRACT

Purpose: Typically developing toddlers extract patterns from their input to add words to their spoken lexicons, yet some evidence suggests that late talkers leverage the statistical regularities of the ambient language differently than do peers. Using the extended statistical learning account, we sought to compare lexical-level statistical features of spoken vocabularies between late talkers and two typically developing comparison groups.
Method: MacArthur–Bates Communicative Developmental Inventories American English Words and Sentences (N = 1,636) were extracted from Wordbank, a database of CDIs. Inventories were divided into three groups: (a) a late talker group (n = 202); (b) a typically developing age-matched group (n = 1,238); and (c) a younger, typically developing group (n = 196) matched to the late talkers on expressive language. Neighborhood density and word frequency were calculated for each word produced by each participant and standardized to z scores. Mixed-effects models were used to evaluate group differences.
Results: The late talker and younger, language-matched groups' spoken vocabularies consist, on standardized average, of words from denser phonological neighborhoods and words higher in frequency of occurrence in parent–child speech, compared to older, typically developing toddlers.
Conclusions: These findings provide support for the extended statistical learning account. Late talkers appear to generally be extracting and using similar patterns from their language input as do younger toddlers with similar levels of expressive vocabulary. This suggests that late talkers may be following a delayed, not deviant, trajectory of expressive language growth.

Late talkers (LTs) are defined as toddlers 18–35 months of age with restricted vocabularies but average nonverbal cognitive abilities as measured by standardized developmental assessments (Paul, 1991; Paul & Jennings, 1992; Rescorla, 1989). Late talking impacts approximately 15% of toddlers (Collisson et al., 2016) and has negative consequences on academic, social, and vocational outcomes (Singleton, 2018).

Inefficient language processing (Fernald et al., 2006; Peter et al., 2019), atypical spoken phonological acquisition (Paul & Jennings, 1992; Thal et al., 1995), and impairments in nonverbal cognition such as attention (MacRoy-Higgins & Montemarano, 2016) have been suggested as sources of late talking. Yet, there remains no unifying theory that provides a mechanistic account for the slowed vocabulary development observed in these toddlers.

Statistical learning theory may afford a framework for better understanding the language acquisition differences observed in LTs (Stokes, 2010; Stokes et al., 2012). Statistical learning is a domain-general cognitive mechanism by which infants and toddlers extract patterns and regularities from visual and auditory input (Aslin, 2017). It is a powerful implicit learning tool that helps infants rapidly acquire a language system. Although statistical

Correspondence to Elizabeth Schoen Simmons: simmonse3@sacredheart.edu. *Disclosure: The authors have declared that no competing financial or nonfinancial interests existed at the time of publication.*

learning is not sufficient for acquiring language, it is one pathway thought likely to contribute to its growth. Most studies of statistical learning in typical infants and toddlers employ an artificial language task that provides exposure to a stream of computer-generated nonsense syllables. Participants are then tested on their ability to distinguish "words" (syllables that always co-occur) from "nonwords" (syllables that rarely or never co-occur) from the input presented. For example, 9-month-old infants were found to differentiate "words" (e.g., *pabiku*) from "nonwords" (e.g., *pakuda*) in a stream of nonsense syllables (e.g., *pabikugolatudaropi*) after only a limited exposure period (Saffran et al., 1996). Around their first birthday, toddlers also use statistical properties of input to learn novel word–object pairs, as evidenced during cross-situational word learning paradigms (Smith & Yu, 2008), in which toddlers track the co-occurrences of presentations between novel words and novel objects and then implicitly determine the likelihood of a given word–object pair occurring together.

Although statistical learning has generally been explored through laboratory-based perception tasks, production studies may provide complementary support for the importance of pattern detection in lexical acquisition. Two such lexical-level patterns that occur in natural languages are phonological neighborhood density (ND) and word frequency (WF). Words are considered phonological neighbors if they differ by a single phonemic deletion, addition, or substitution (referred to as the DAS rule; Luce & Pisoni, 1998). Thus, for the word "mat," the words "at," "mast," and "cat" are considered phonological neighbors. Words can be part of dense (i.e., with many phonological neighbors) or sparse (i.e., with few phonological neighbors) phonological neighborhoods. Unlike in perception where phonologically similar words compete for recognition (Allopenna et al., 1998), in production, phonological similarity is thought to provide a supportive effect (Vitevitch, 2002). ND provides a metric of how many lexical entries have a similar phonological structure; WF, on the other hand, provides an index of how often a word is heard within linguistic input. Increased exposure to a word form may impact whether the word is acquired (Rice et al., 1994). Taken together, both ND and WF provide measures of the ways in which toddlers may use patterns in their input to add new lexical entries to their spoken vocabularies.

Analyses of parent questionnaires of toddler vocabulary and vocabulary transcriptions of parent–child interactions that have measured both ND and WF provide evidence that very young children leverage pattern detection to acquire early words. Dollaghan (1994) reported that the majority of words within the spoken lexicons of 1- to 3-year-olds had greater than two phonological neighbors, based on a database analysis of parent checklists of toddler vocabulary. Coady and Aslin (2003) transcribed short play sessions between toddlers and their parents and found that toddlers' productive vocabularies included words that resided in denser phonological neighborhoods compared to their parents' word neighborhoods. Thus, there is some evidence that toddlers use the statistical pattern of ND to add words to their spoken vocabulary.

Regarding WF, concrete nouns are some of the earliest lexical entries acquired (E. Bates et al., 1994), with WF predicting their age of acquisition (Braginsky et al., 2016; Storkel, 2004). S. D. Jones and Brandt (2019) used Bayesian regression to model productive vocabularies in 300 English-speaking, 1- to 2-year-olds and found that words heard most often were more commonly reported by parents to be both comprehended and produced by toddlers. Similar results were found using audio and video recordings of 9- to 24-month-old infants and toddlers collected longitudinally. Roy et al. (2009) reported that the more frequently a word was heard by the toddler, the earlier the word was added to the productive lexicon across all grammatical classes of words.

Impoverished statistical learning has been implicated in the language difficulties observed in older children with language impairments (see Lammertink et al., 2017, for a review). School-aged children and adolescents with developmental language disorder (DLD) are less accurate in extracting the transitional probabilities from a speech stream of nonsense syllables compared to same-age controls (Evans et al., 2009; Hsu et al., 2014). Preschoolers with DLD also showed a disadvantage in recognizing new words in statistical learning paradigms when presented with an artificial language, compared to school-aged peers (Haebig et al., 2017). These empirical studies provide emerging evidence that language delayed preschoolers and older children with language disorders may have limitations in their ability to detect statistical regularities in language input for acquiring new word meanings. Still, like the other studies reviewed above, these experiments did not examine the effects of these differences on lexical selection in word production. Thus, the examination of WF and ND on young children's ability to produce words can help expand our understanding of their role in language acquisition.

There are treatment protocols, such as Vocabulary Acquisition and Usage for Late Talkers (VAULT; Alt et al., 2020; Munro et al., 2021), that leverage techniques such as focused stimulation, which operates under the assumptions of statistical learning (e.g., providing variable language input relative to speaker, context, and referents where toddlers must implicitly learn the patterns). Results of these treatment studies show positive changes to toddlers' expressive language skills. Yet, observational studies suggest that toddlers with small expressive vocabularies may be overly and more persistently reliant on early leveraged statistical cues, which could have a cascading effect on the ability to add new words to spoken lexicons. Stokes (2010) and Stokes et al. (2012) used a small corpus of MacArthur–Bates Communicative Developmental Inventories (CDI; Fenson et al., 2007) to evaluate both ND and WF in British-English– and French-speaking toddlers divided into "average" versus "below-average" word producers. They limited their analyses of words to monosyllabic nouns, verbs, adverbs, and adjectives. They found that below-average producers' vocabularies included words higher in ND and lower in WF compared to average producers. Subsequently, they attributed their findings to what they coined the extended statistical learning account (ESLA), which holds that LTs were slower to take advantage of the statistical patterns of their input and then slower to expand pattern detection to unfamiliar input patterns (Stokes et al., 2012).

The present study seeks to extend the findings of Stokes (2010) and Stokes et al. (2012) by evaluating lexical regularities in late-talking toddlers and two typically developing (TD) toddler groups using (a) a large database sample of parent questionnaires measuring spoken vocabularies collected from the CDI (Fenson et al., 2007) and (b) the inclusion of a younger group of TD toddlers matched on expressive language level to the LTs. By doing this, we will begin to determine whether LTs are using pattern extraction strategies that are similar or dissimilar to their productive vocabulary-matched counterparts. If the ESLA explains the slow vocabulary growth in LTs, we would expect their ND and WF properties to be more similar to their younger, language-matched peers than to typical age-mates.

Method

Data Acquisition and Reduction

We extracted 2,174 CDI: Words and Sentences American English forms (CDI:WS; Fenson et al., 2007) from the Wordbank database (Frank et al., 2017), an online, open-source database of CDI. This study was exempt from the institutional review board process as the data are readily available to the public in anonymized form. The CDI are a family of parent report questionnaires, available in several languages, designed to measure early gesture, vocabulary, and grammar development. We selected the Words and Sentences form normed for toddlers ages 16–30 months (our age group of interest), restricted our selection to only the American English form, and then eliminated inventories for toddlers with no words (n = 4). The CDI:WS provides parents a checklist of vocabulary words loosely organized by syntactic categories. Parents simply indicate which words the child is currently producing on a regular basis.

The CDI:WS contains 668 word forms. Of these possible words, we constrained our analysis to monosyllabic words. Our motivation for doing so was twofold: (a) Longer words have few, if any, phonological neighbors (e.g., "elephant," "crayon," "blanket"), and (b) previous literature has focused on monosyllabic words, thus making between-study comparisons more straightforward (Coady & Aslin, 2003; Dollaghan, 1994; Stokes, 2010; Stokes et al., 2012). After constraining data to single-syllable words (n = 400), we eliminated nonword sound effects (e.g., "ouch," "moo"; n = 4) and idiosyncratic proper nouns (e.g., pet's name, babysitter's name; n = 3). Duplicates of word tokens such as "watch" (object) and "watch" (action) were counted once (n = 9). This left a possible 384 words for analysis including noun, verb, adverb, adjective, preposition, social (e.g., "hi," "bye"), and function (e.g., "yes," "no") word classes.

ND and WF

An ND metric and a WF metric were assigned to each word produced by every participant from the analysis set of 384 words. ND was derived from the Irvine Phonotactic Online Dictionary, Version 2.0 (IPhOD; Vaden et al., 2009). IPhOD calculates estimates for phonotactics using approximately 54,000 American English words. Words were considered phonological neighbors if they differed by one phoneme using the DAS rule (Luce & Pisoni, 1998). The smaller the ND metric, the fewer phonological neighbors a word had within the IPhOD lexicon. For example, the word "brush" had the fewest phonological neighbors (n = 6, ND metric = 6), whereas the word "see" had the greatest number of phonological neighbors (n = 56, ND metric = 56).

WF was calculated using data from the Child Language Data Exchange System Database (CHILDES-DB) and the CHILDES-R package using procedures outlined by Sanchez et al. (2019), which calculates the number of times a word was used (per million) in child-directed parent speech in a sample of parent–child interactions with toddlers ages 12 and 30 months. For example, the word "skate" was produced by parents least frequently during these dyadic interactions (820 tokens/million words), whereas the word "you" was produced most frequently (46,945 tokens/million words). CHILDES-DB was selected over SUBTLEXus (Brysbaert & New, 2009) as it provides a better estimate of word forms heard by toddlers, whereas SUBTLEXus frequencies are extracted from

American English movies and television series subtitles and likely do not represent the type of language input heard by our target age group. After ND and WF were calculated for each word, they were standardized using a *z*-score transformation following Stokes (2010) and Storkel (2004) as the absolute values for ND and WF were on differing scales.

Inventory Groups

Inventories were selected and divided into three groups based on chronological age and spoken vocabulary size (N = 1,636). The LT group (n = 202) included toddlers ages 21–30 months who scored at or below the 15th percentile on the CDI:WS. We constrained the age range for this group and selected a cutoff of 1 *SD* below the mean (≤ 15th percentile) based on the extant literature on LTs (Collisson et al., 2016; Curtis et al., 2023; Ellis et al., 2015; Horvath et al., 2019; MacRoy-Higgins & Montemarano, 2016; MacRoy-Higgins et al., 2013; Weismer et al., 2011). Two TD groups were used for comparison. A TD age-matched group (TDA; n = 1,238) was matched on chronological age to the LT group. We also included a TD language-matched group (TDL; n = 196) that was matched to the LT group on number of spoken words produced as measured by the CDI:WS. These participants were between 16 and 17 months of age (MacRoy-Higgins et al., 2013; Thal et al., 1995). Both TD groups had spoken vocabularies at or above the 30th percentile for their age. There is no consensus in the literature relative to CDI:WS cutoff scores for TD toddlers, with some studies using the 20th percentile (Curtis et al., 2023), other studies using a more stringent cutoff of the 35th percentile (MacRoy-Higgins et al., 2013), and others simply reporting the number of spoken words produced on the instrument and not including percentile rank cutoff scores (Horvath et al., 2019). We selected a cutoff of ≥ 30th percentile on the CDI:WS for our TD groups (Sosa & Stoel-Gammon, 2012) to minimize inclusion of potential LTs in these typical groups and to ensure that the TDL and LT groups were well matched on the number of spoken words produced. Pairwise comparisons showed no significant differences between the LT and TDA groups on chronological age (p = .50) or between the LT and TDL groups on mean number of monosyllabic words produced (p = .75). The sample was roughly split between males and females, and the maternal education level across groups consisted mostly of some college or additional education. See Table 1 for details.

Analysis Plan

Two different mixed-effects models were used to evaluate group-level differences for z score ND (z-ND) and z score WF (z-WF). Group (LT, TDL, TDA) was used as the fixed effect in the model, whereas either z-ND or z-WF was used as the dependent variable. Participant was included as the random effect (intercepts) for both models. We only included random intercepts as the models would not converge when random slopes were added (Barr et al., 2013).

Analyses were conducted in R (Version 1.1.463; R Core Team, 2020) using the *lme4* package (Version 1.1-21; D. Bates et al., 2015) for multilevel modeling. The *lmerTest* package (Version 3.10; Kuznetsova et al., 2017) was employed to evaluate main effects, and the *emmeans* package (Version 1.4.6; Lenth et al., 2020) was used to explore planned comparisons.

Table 1. Demographics and expressive vocabulary by group.

Variable	Group			One-way ANOVA			*p* values from pairwise comparisons or χ^2		
	TDA (n = 1,238)	TDL (n = 196)	LT (n = 202)	*df*	*F*	*p*	TDA vs. TDL	TDA vs. LT	TDL vs. LT
Chronological age in months, *M* (*SD*)	25.75 (2.50)	16.43 (0.49)	25.55 (2.33)	2, 1633	1,369.00	< .001	< .001	.50	< .001
Male, %	51%	49%	53%	—	—	—	.76	.54	.48
With maternal education ≥ some college, %	81%	85%	69%	—	—	—	< .001	< .001	< .001
CDI:WS percentile, *M* (*SD*)	66% (20%)	60% (20%)	8% (4%)	2, 1633	791.40	< .001	< .001	< .001	< .001
No. of monosyllabic words produced on CDI:WS, *M* (*SD*)	260 (81)	56 (48)	50 (40)	2, 1633	1,181.00	< .001	< .001	< .001	.75

Note. Numbers in parentheses are standard deviations. Em dashes indicate values not provided by analyses. ANOVA = analysis of variance; TDA = typically developing age-matched group; TDL = typically developing language-matched group; LT = late talker; CDI:WS = MacArthur–Bates Communicative Developmental Inventories: Words and Sentences (Fenson et al., 2007).

Results

ND

There was a significant main effect of group, $F(2, 34384) = 380.77$, $p < .001$, on z-ND. Both the LT ($M = 0.75$, $SD = 0.20$, z ratio = 20.68, $p < .001$) and TDL ($M = 0.75$, $SD = 0.19$, z ratio = 18.91, $p < .001$) groups' expressive vocabularies included words from denser phonological neighborhoods, as measured by standardized average, compared to the TDA group ($M = 0.50$, $SD = 0.05$). No significant difference in z-ND between the LT and TDL groups ($p = .18$) was observed (see Figure 1a).

WF

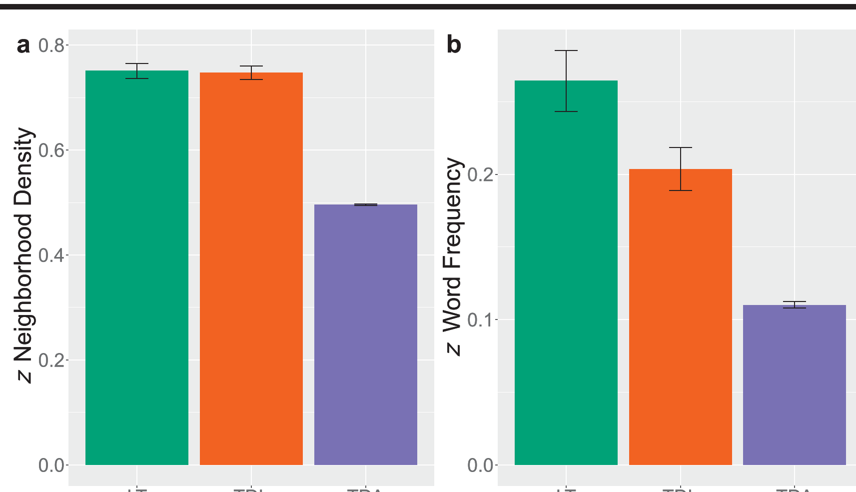
A significant main effect of group on z-WF was also present, $F(2, 34384) = 20.13$, $p < .001$. Both the LT ($M = 0.26$, $SD = 0.30$, z ratio = 7.66, $p < .001$) and TDL ($M = 0.20$, $SD = 0.21$, z ratio = 4.88, $p < .05$) groups' expressive vocabularies had a higher standardized average on WF compared to the TDA group ($M = 0.11$, $SD = 0.08$). There was also a significant difference in z-WF between the LT and TDL groups (z ratio = 2.39, $p < .05$), such that LTs produced words with higher standardized frequency scores compared to their language-matched peers (see Figure 1b).

Discussion

This study evaluated the properties of toddlers' spoken vocabularies obtained from a large database of parent questionnaires. Based on the ESLA (Stokes, 2010; Stokes et al., 2012), we hypothesized that the late-talking participants add words to their spoken vocabularies by leveraging patterns in their ambient language input in a manner similar to that of younger children matched on expressive vocabulary size. Our findings partially support this hypothesis in that both LTs and their younger, typical counterparts' expressive vocabularies consist of words from denser phonological neighborhoods compared to TD, older toddlers. Yet, we also saw a significant difference between LTs and the spoken vocabulary–matched group on WF. That is, language-delayed toddlers appear to be producing words with even higher average standardized frequency scores than language-matched younger children. These findings, we believe, lend support to existing literature that suggests less efficient statistical learning as one aspect of the profile of children with language disorders, which this study extends down to the LT population. Thus, we observe that LTs present with a delay, an extended reliance on some statistical features, and a difference in their use of statistical patterns, in that they require even more input than language-matched toddlers to produce new words.

Again, our study extended the findings (Stokes, 2010; Stokes et al., 2012) that early spoken vocabulary consists of words from phonologically dense neighborhoods by comparing the language-delayed toddlers to both age-matched and expressive language–matched peers. Both LTs and toddlers with matched levels of expressive language produce words from similarly dense phonological neighborhoods suggesting that LTs' ability to say new words is influenced by their phonotactic structure in a manner similar to that seen in younger toddlers with like levels of expressive language. Older toddlers with typical expressive vocabulary sizes, on the other hand, are producing words from less

Figure 1. Bar plots of z-transformed mean neighborhood density (a) and mean word frequency (b) by group. LT = late talker; TDL = typically developing language-matched group; TDA = typically developing age-matched group.



dense neighborhoods compared to the LTs and younger typical toddlers. These findings may also suggest that young toddlers and those with language delays make use of the phonological shapes of words as building blocks of early vocabulary. Growth in vocabulary, particularly in the "word spurt" stage that occurs around 18–24 months in typical development, would seem to require the toddler to expand beyond the most common phonological shapes available in dense neighborhoods.

Experimental studies of word learning in typical preschoolers highlight the facilitatory effect of ND, with high-ND words more readily learned than words in low-density neighborhoods (Hoover et al., 2010; Storkel et al., 2013). It is argued that as a new word form is heard, its phonological neighbors stored in memory are activated. If the new word form has many phonological neighbors, preexisting word forms may act as templates that provide memory support as new phonologically similar forms are consolidated into underlying representations. Recent computational work also supports this hypothesis. Using data derived from CHILDES (MacWhinney, 2000), models that included ND, WF, word length, and phonotactic probability simulated word acquisition in human infants and showed an advantage for acquisition of high-ND word forms (G. Jones et al., 2021).

With regard to WF, although both the LTs and language-matched toddlers produce words heard more often in their ambient language compared to older, language-typical children, LTs' vocabularies consisted of a greater proportion of high-frequency words, even when compared to younger toddlers with similar expressive vocabulary sizes. Although this finding represents a difference, it bolsters the suggestion that statistical learning may be less efficient in LTs, as they appear to require prolonged exposure to word forms before they are added to the spoken lexicon, more so than even language-matched peers. Studies of novel word learning in LTs have shown that they are less efficient at mapping a new word form to its referent, given the same amount of input, compared to age-matched typical peers (MacRoy-Higgins & Montemarano, 2016; Weismer et al., 2013). These findings differ from those of Stokes (2010) and Stokes et al. (2012), however. The source of this variation may be the inclusion criteria for words selected for analyses. Stokes limited the words analyzed to what was described as "core vocabulary," primarily nouns, verbs, and adjectives. Our analysis included all monosyllabic words, including prepositions as well as social and functional words, as elimination of these high-frequency word categories may not provide a full picture of the statistical strategies used by LTs.

Although nouns as a class are learned earliest, they are, individually, lower in frequency than closed-class words (Goodman et al., 2008). Our findings showing that LTs produce words higher in frequency, even when compared to expressive language–matched peers, suggest a stronger-than-typical reliance on these most often–heard terms. At least one study of LTs suggests their expressive vocabularies have a lower proportion of nouns compared to TD toddlers matched on expressive language or chronological age (MacRoy-Higgins et al., 2016). As noted, nouns are a common class of first words (Lahey, 1988), but more social words such as "hi" and "bye," negation ("no"), some verbs such as "go," and prepositions such as "in" and "on" are also very high in frequency in toddler lexicons and often appear in children's first 50 spoken words (Lahey, 1988). Another vocabulary study of LTs, using the Language Development Survey (Rescorla, 1989), found that late-talking 2-year-olds with a greater proportion of nouns in their spoken lexicons had larger vocabularies when tested at 3 years of age. Our results may reflect this heterogeneity within the population of LTs, such that some may be relying more heavily on closed-class and function words heard with very high frequency in child-directed speech.

Limitations

There are limitations of using database-derived samples. We do not know the developmental profiles of our toddlers; thus, it is possible that some of our LTs may have other developmental conditions and/or receptive language delays in addition to small spoken vocabularies. This database also does not provide any information on race or ethnicity. Additionally, although parents are experts on their child's language development skills, we do not have a way to confirm validity of these parent reports. Finally, our sample generally consists of participants whose mothers have completed at least some college. This highly educated sample represents a relatively narrow subset of the general population, which makes these findings less generalizable. We also appreciate that these participants may not represent the ethnic and racial distribution of the entire population of American English talkers. Follow-up studies should include a more diverse sample to ensure findings are generalizable to the population as a whole, as well as more in-depth participant characterization with regard to demographics, nonverbal cognition, and receptive skills. Despite these limitations, the use of databases yields large samples that are generally difficult to acquire otherwise. It also provides opportunities for reproducibility studies and for preliminary tests of a variety of hypotheses regarding language development.

Clinical Implications

These findings have the potential to impact our thinking about interventions for LTs. First, the role of dense phonological neighborhoods, corroborated by findings using this same database examining lexical selection in relation to productive phonological repertoires (Simmons & Paul, 2023), emphasizes the importance of considering phonological shape when adding to the spoken lexicon of LTs in therapeutic settings. Our findings could be interpreted to suggest that facilitating production of new words in LTs initially by choosing those that contain phonemes and word shapes (e.g., consonant–vowel [CV], VC, CVC) common to words they already say. Eliciting production of words with new phonemes and syllable shapes may follow, as studies of both speech (Gierut, 2001) and language therapy (Thompson, 2007) for older children suggest that "challenging" a delayed system to increase its complexity is an effective spur to development.

Our WF findings also support also this suggestion. In early phases of therapy for LTs, therapists might encourage production of high-frequency social and function words, rather than relying on less frequent noun tokens alone, combined with structured intensive input of less frequent but child-relevant words in play-based language stimulation activities. Such activities have been shown to increase language comprehension (e.g., Tarvainen et al., 2020) and may also solidify emerging phonological representations for later production.

In the course of this intervention, clinicians might first add intensified input and later the elicitation of less frequent, age-appropriate words, using approaches such as milieu communication teaching (Fey et al., 2016), focused stimulation (e.g., VAULT; Alt et al., 2020), and elicited imitation. These therapeutic activities, we suggest, would serve to not only enhance the child's expressive vocabulary but also, through the exposure to more phonologically complex and less frequent words in the input phases of the intervention, provide the opportunity for the child to understand and build phonological representations for a broader set of words that can serve as a basis for production activities in later phases.

Conclusions

We found partial support for the ESLA for LTs as they produce words from denser phonological neighborhoods than typical age-matched peers, as younger language-matched children do. This suggests that LTs may weigh the phonological features of words more heavily than their older TD peers when acquiring a spoken lexicon. Yet, LTs' vocabularies also consist of words that are more frequently heard compared to age-matched peers and are even more limited to highly frequent words than language-matched typical toddlers. Taken together, the findings of persisting constraints regarding ND and overreliance on WF in LTs may further slow their language development. These results suggest limitations in LTs' leveraging of statistical patterns when adding words to their spoken vocabularies. Clinical practice can be informed by considering the implications of these limitations for early vocabulary intervention.

Data Availability Statement

The data set that was generated for analyses in this article is available from the Wordbank repository, https://wordbank.stanford.edu/data.

Acknowledgments

This article was written using support from the National Institute on Deafness and Other Communication Disorders under Award R15DC020290 (PI: Elizabeth Schoen Simmons).

References

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*(4), 419–439. https://doi.org/10.1006/jmla.1997.2558

Alt, M., Mettler, H. M., Erikson, J. A., Figueroa, C. R., Etters-Thomas, S. E., Arizmendi, G. D., & Oglivie, T. (2020). Exploring input parameters in an expressive vocabulary treatment with late talkers. *Journal of Speech, Language, and Hearing Research, 63*(1), 216–233. https://doi.org/10.1044/2019_JSLHR-19-00219

Aslin, R. N. (2017). Statistical learning: A powerful mechanism that operates by mere exposure. *WIRES Cognitive Science, 8*(1–2), Article e1373. https://doi.org/10.1002/wcs.1373

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., Machler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67,* 1–48. https://doi.org/10.18637/jss.v067.i01

Bates, E., Marchman, V., Thal, D., Fenson, L., Dale, P., Reznick, J. S., Reilly, J., & Hartung, J. (1994). Developmental and stylistic variation in the composition of early vocabulary. *Journal of Child Language, 21*(1), 85–123. https://doi.org/10.1017/S0305000900008680

Braginsky, M., Yurovsky, D., Marchman, V. A., & Frank, M. (2016). From uh-oh to tomorrow: Predicting age of acquisition for early words across languages. In A. Papafragou, D. Grodner, D. Mirman, & J. Trueswell (Eds.), *Proceedings of the Annual Meeting of the Cognitive Science Society* (pp. 1691–1696). Cognitive Science Society.

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*(4), 977–990. https://doi.org/10.3758/BRM.41.4.977

Coady, J. A., & Aslin, R. N. (2003). Phonological neighbourhoods in the developing lexicon. *Journal of Child Language, 30*(2), 441–469. https://doi.org/10.1017/S0305000903005579

Collisson, B. A., Graham, S. A., Preston, J. L., Rose, M. S., McDonald, S., & Tough, S. (2016). Risk and protective factors for late talking: An epidemiologic investigation. *The Journal of Pediatrics, 172,* 168–174.e1. https://doi.org/10.1016/j.jpeds.2016.02.020

Curtis, P. R., Estabrook, R., Roberts, M. Y., & Weisleder, A. (2023). Specificity of phonological representations in U.S. English-speaking late talkers and typical talkers. *Infancy, 28*(4), 771–792. https://doi.org/10.1111/infa.12536

Dollaghan, C. A. (1994). Children's phonological neighbourhoods: Half empty or half full? *Journal of Child Language, 21*(2), 257–271. https://doi.org/10.1017/s0305000900009260

Ellis, E. M., Borovsky, A., Elman, J. L., & Evans, J. L. (2015). Novel word learning: An eye-tracking study. Are 18-month-old late talkers really different from their typical peers? *Journal of Communication Disorders, 58,* 143–157. https://doi.org/10.1016/j.jcomdis.2015.06.011

Evans, J. L., Saffran, J. R., & Robe-Torres, K. (2009). Statistical learning in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 52*(2), 321–335. https://doi.org/10.1044/1092-4388(2009/07-0189)

Fenson, L., Bates, E., Dale, P. S., Marchman, V. A., Reznick, J. S., & Thal, D. J. (2007). *MacArthur–Bates Communicative Development Inventories*. Brookes.

Fernald, A., Perfors, A., & Marchman, V. A. (2006). Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. *Developmental Psychology, 42*(1), 98–116. https://doi.org/10.1037/0012-1649.42.1.98

Fey, M., Warren, S., Bredin-Oja, S., & Yoder, P. (2016). Responsivity education/prelinguistic milieu teaching. In R. McCauley, M. Fey, & R. Gillam (Eds.), *Treatment of language disorders in children* (2nd ed., pp. 57–86). Brookes.

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2017). Wordbank: An open repository for developmental vocabulary data. *Journal of Child Language, 44*(3), 677–694. https://doi.org/10.1017/S0305000916000209

Gierut, J. A. (2001). Complexity in phonological treatment: Clinical factors. *Language, Speech, and Hearing Services in Schools, 32*(4), 229–241. https://doi.org/10.1044/0161-1461(2001/021)

Goodman, J. C., Dale, P. S., & Li, P. (2008). Does frequency count? Parental input and the acquisition of vocabulary. *Journal of Child Language, 35*(3), 515–531. https://doi.org/10.1017/S0305000907008641

Haebig, E., Saffran, J. R., & Weismer, S. E. (2017). Statistical word learning in children with autism spectrum disorder and specific language impairment. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 58*(11), 1251–1263. https://doi.org/10.1111/jcpp.12734

Hoover, J. R., Storkel, H. L., & Hogan, T. P. (2010). A cross-sectional comparison of the effects of phonotactic probability and neighborhood density on word learning by preschool children. *Journal of Memory and Language, 63*(1), 100–116. https://doi.org/10.1016/j.jml.2010.02.003

Horvath, S., Rescorla, L., & Arunachalam, S. (2019). The syntactic and semantic features of two-year-olds' verb vocabularies: A comparison of typically developing children and late talkers. *Journal of Child Language, 46*(3), 409–432. https://doi.org/10.1017/S0305000918000508

Hsu, H. J., Tomblin, J. B., & Christiansen, M. H. (2014). Impaired statistical learning of non-adjacent dependencies in adolescents with specific language impairment. *Frontiers in Psychology, 5,* Article 175. https://doi.org/10.3389/fpsyg.2014.00175

Jones, G., Cabiddu, F., Andrews, M., & Rowland, C. (2021). Chunks of phonological knowledge play a significant role in children's word learning and explain effects of neighborhood size, phonotactic probability, word frequency and word length. *Journal of Memory and Language, 119,* Article 104232. https://doi.org/10.1016/j.jml.2021.104232

Jones, S. D., & Brandt, S. (2019). Do children really acquire dense neighbourhoods? *Journal of Child Language, 46*(6), 1260–1273. https://doi.org/10.1017/S0305000919000473

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Lahey, M. (1988). *Language disorders and language development*. Macmillan.

Lammertink, I., Boersma, P., Wijnen, F., & Rispens, J. (2017). Statistical learning in specific language impairment: A meta-analysis. *Journal of Speech, Language, and Hearing Research, 60*(12), 3474–3486. https://doi.org/10.1044/2017_jslhr-l-16-0439

Lenth, R., Singmann, H., Love, J., Buerkner, P., & Herve, M. (2020). *Package "Emmeans"* (R package Version 1.4.8) [Computer software]. http://cran.r-project.org/package=emmeans

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19*(1), 1–36. https://doi.org/10.1097/00003446-199802000-00001

MacRoy-Higgins, M., & Montemarano, E. A. (2016). Attention and word learning in toddlers who are late talkers. *Journal of Child Language, 43*(5), 1020–1037. https://doi.org/10.1017/S0305000915000379

MacRoy-Higgins, M., Schwartz, R. G., Shafer, V. L., & Marton, K. (2013). Influence of phonotactic probability/neighbourhood density on lexical learning in late talkers. *International Journal of Language and Communication Disorders, 48*(2), 188–199. https://doi.org/10.1111/j.1460-6984.2012.00198.x

MacRoy-Higgins, M., Shafer, V., Fahey, K., & Kaden, E. (2016). Vocabulary of toddlers who are late talkers. *Journal of Early Intervention, 38*(2), 118–129. https://doi.org/10.1177/1053815116637620

MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk: Transcription format and programs* (3rd ed.). Erlbaum.

Munro, N., Baker, E., Masso, S., Carson, L., Lee, T., Wong, A. M., & Stokes, S. F. (2021). Vocabulary acquisition and usage for late talkers treatment: Effect on expressive vocabulary and phonology. *Journal of Speech, Language, and Hearing Research, 64*(7), 2682–2697. https://doi.org/10.1044/2021_JSLHR-20-00680

Paul, R. (1991). Profiles of toddlers with slow expressive language development. *Topics in Language Disorders, 11*(4), 1–13. https://doi.org/10.1097/00011363-199111040-00003

Paul, R., & Jennings, P. (1992). Phonological behavior in toddlers with slow expressive language development. *Journal of Speech and Hearing Research, 35*(1), 99–107. https://doi.org/10.1044/jshr.3501.99

Peter, M. S., Durrant, S., Jessop, A., Bidgood, A., Pine, J. M., & Rowland, C. F. (2019). Does speed of processing or vocabulary size predict later language growth in toddlers? *Cognitive Psychology, 115,* Article 101238. https://doi.org/10.1016/j.cogpsych.2019.101238

R Core Team. (2020). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Rescorla, L. (1989). The Language Development Survey: A screening tool for delayed language in toddlers. *Journal of Speech and Hearing Disorders, 54*(4), 587–599. https://doi.org/10.1044/jshd.5404.587

Rice, M. L., Oetting, J. B., Marquis, J., Bode, J., & Pae, S. (1994). Frequency of input effects on word comprehension of children with specific language impairment. *Journal of Speech and Hearing Research, 37*(1), 106–122. https://doi.org/10.1044/jshr.3701.106

Roy, B. C., Frank, M. C., & Roy, D. (2009). Exploring word learning in a high-density longitudinal corpus. *Proceedings of the Meeting of the Annual Cognitive Science Society, 31,* 2106–2111.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Sanchez, A., Meylan, S. C., Braginsky, M., MacDonald, K. E., Yurovsky, D., & Frank, M. C. (2019). childes-db: A flexible and reproducible interface to the child language data exchange system. *Behavior Research Methods, 51*(4), 1928–1941. https://doi.org/10.3758/s13428-018-1176-7

Simmons, E. S., & Paul, R. (2023, November). *Phonological features of the spoken lexicon in late talkers: Delayed or different*? [Paper presentation]. Annual Convention of the American Speech-Language-Hearing Association, Boston, MA.

Singleton, N. C. (2018). Late talkers: Why the wait-and-see approach is outdated. *Pediatric Clinics of North America, 65*(1), 13–29. https://doi.org/10.1016/j.pcl.2017.08.018

Smith, L., & Yu, C. (2008). Infants rapidly learn word-referent mappings via cross-situational statistics. *Cognition, 106*(3), 1558–1568. https://doi.org/10.1016/j.cognition.2007.06.010

Sosa, A. V., & Stoel-Gammon, C. (2012). Lexical and phonological effects in early word production. *Journal of Speech, Language, and Hearing Research, 55*(2), 596–608. https://doi.org/10.1044/1092-4388(2011/10-0113)

Stokes, S. F. (2010). Neighborhood density and word frequency predict vocabulary size in toddlers. *Journal of Speech, Language, and Hearing Research, 53*(3), 670–683. https://doi.org/10.1044/1092-4388(2009/08-0254)

Stokes, S. F., Kern, S., & Dos Santos, C. (2012). Extended statistical learning as an account for slow vocabulary growth. *Journal of Child Language, 39*(1), 105–129. https://doi.org/10.1017/S0305000911000031

Storkel, H. L. (2004). The emerging lexicon of children with phonological delays: Phonotactic constraints and probability in acquisition. *Journal of Speech, Language, and Hearing Research, 47*(5), 1194–1212. https://doi.org/10.1044/1092-4388(2004/088)

Storkel, H. L., Bontempo, D. E., Aschenbrenner, A. J., Maekawa, J., & Lee, S. (2013). The effect of incremental changes in phonotactic probability and neighborhood density on word learning by preschool children. *Journal of Speech, Language, and Hearing Research, 56*(5), 1689–1700. https://doi.org/10.1044/1092-4388(2013/12-0245)

Tarvainen, S., Stolt, S., & Launonen, K. (2020). Oral language comprehension interventions in 1–8-year-old children with language disorders or difficulties: A systematic scoping review. *Autism & Developmental Language Impairments, 5*. https://doi.org/10.1177/2396941520946999

Thal, D., Oroz, M., & McCaw, V. (1995). Phonological and lexical development in normal and late-talking toddlers. *Applied Psycholinguistics, 16*(4), 407–424. https://doi.org/10.1017/S0142716400066017

Thompson, C. K. (2007). Complexity in language learning and treatment. *American Journal of Speech-Language Pathology, 16*(1), 3–5. https://doi.org/10.1044/1058-0360(2007/002)

Vaden, K. I., Halpin, H. R., & Hickok, G. S. (2009). *Irvine Phonotactic Online Dictionary, Version 2.0* [Data file]. http://www.iphod.com

Vitevitch, M. S. (2002). The influence of phonological similarity neighborhoods on speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(4), 735–747. https://doi.org/10.1037//0278-7393.28.4.735

Weismer, S. E., Venker, C. E., Evans, J. L., & Moyle, M. J. (2013). Fast mapping in late-talking toddlers. *Applied Psycholinguistics, 34*(1), 69–89. https://doi.org/10.1017/S0142716411000610