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Influence of phonotactic probability/neighbourhood density on lexical learning in late talkers

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Abstract

Background—Toddlers who are late talkers demonstrate delays in phonological and lexical skills. However, the influence of phonological factors on lexical acquisition in toddlers who are late talkers has not been examined directly.

Aims—To examine the influence of phonotactic probability/neighbourhood density on word learning in toddlers who were late talkers using comprehension, production and word recognition tasks.

Methods & Procedures—Two-year-olds who were late talkers ($n = 12$) and typically developing toddlers ($n = 12$) were exposed to 12 novel pseudo-words for unfamiliar objects in ten training sessions. Pseudo-words contained high or low phonotactic probability English sound sequences. The toddlers' comprehension, speech production and detection of mispronunciation of the newly learned words were examined using a preferential looking paradigm.

Outcomes & Results—Late talkers showed poorer performance than toddlers with typical language development in all three tasks: comprehension, production and detection of mispronunciations. The toddlers with typical language development showed better speech production and more sensitivity to mispronunciations for high than low phonotactic probability/neighbourhood density sequences. Phonotactic probability/neighbourhood density did not influence the late talkers' speech production or sensitivity to mispronunciations; they performed similarly for pseudo-words with high and low phonotactic probability/neighbourhood density sound sequences.

Conclusions & Implications—The results indicate that some late talkers do not recognize statistical properties of their language, which may contribute to their slower lexical learning.

Keywords

late talkers; phonology; lexicon; language delay

Introduction

Approximately 15% of toddlers have slow expressive language development, in the absence of cognitive, hearing, social, and physical disorders, and are labelled late talkers (LT) (Rescorla 1989). Some LT appear to catch up with their peers, whereas others continue to exhibit language delays and deficits and are diagnosed with specific language impairment (SLI) (e.g. Leonard 2000). Even though standardized tests indicate normal language abilities in these late bloomers, they often demonstrate difficulties language skills such as syntax (Nippold *et al.* 2009) and with language-based skills such as reading (Rescorla 2009). The factors contributing to initial language delay or predictive of later language outcome are currently unknown, though comprehension abilities and early phonology skills have been suggested as possible predictors of outcomes (e.g. Carson *et al.* 2003, Tomblin *et al.* 2003, Schoon *et al.* 2010). The present study examined the influence of phonological regularities (i.e. phonotactic probability) on lexical acquisition in toddlers identified as LT.

Lexical and phonological development in late talkers (LT)

Some toddlers who are LT can have atypical patterns in phonological development (e.g. Rescorla and Ratner 1996, Williams and Elbert 2003), which are observed before they produce their first words. For instance, less canonical babbling is observed between 10 and 12 months as compared with infants with typical language development (TLD) (Oller *et al.* 1999). Phonological delays can continue once LT begin to produce their first words; they produce less complex syllable structures, produce fewer correct consonants and have a smaller phonemic inventory as compared with their peers with TLD (Rescorla and Ratner 1996). Atypical phonological patterns such as increased sound variability and atypical phoneme substitutions have also been reported (Williams and Elbert 2003). It is likely that the phonological deficits observed in toddlers who are LT contribute to their lexical delay.

Ellis Weismer and Evans (2002) attributed the poor word learning by toddlers who were LT to weak phonological representations; however, their study only showed that toddlers who were LT performed more poorly on fast-mapping word learning than age-matched controls. Similar findings of poor word learning are observed in older children (3–6 years) with SLI (e.g. Leonard *et al.* 1987, Alt and Plante 2006, Gray 2004), but only the study by Leonard and colleagues directly examined the relationship between a child's phonology and word learning. Leonard *et al.* (1987) taught new words to preschool children with SLI that contained phonological forms that the children produced (IN), did not produce or attempt (OUT), or attempted to produce (ATTEMPTED) in their spontaneous speech. They found that unlike their peers with TLD, children with SLI did not take advantage of the phonological characteristic of their existing lexicon when learning new words. In summary, toddlers who are LT demonstrate phonological and lexical delays. However, the influence of phonological factors such as the detail of phonological representations on lexical acquisition in toddlers who are LT has not been examined directly.

Phonological and lexical influences on word learning

Connectionist models can be used as a framework to examine the influence of phonology on the lexicon in toddlers who are LT (e.g. Storkel and Morrisette 2002). Each lexical item has a *resting threshold*, which is dependent upon how frequent that particular word is activated; frequently occurring words are more easily accessed and produced than less frequently occurring words because these forms have been either heard or produced more often. Likewise, each phonological form has a resting threshold, which is influenced by how frequently it appears in a given language, sounds that are common in a language have a higher resting threshold than sounds that are rare.

The statistical properties of phonological information are derived from the lexicon. The frequency of segments and segmental sequence patterns (phonotactics) in a child's lexicon is dependent on the number of words in that child's lexicon. The phonotactic probability is computed for the frequencies of these patterns (e.g. probability of [c] followed by [a] in words such as *cop*, *cot*). The number of words that are phonologically similar to a given word (i.e. neighbourhood density) is related to phonotactic probability (Jusczyk *et al.* 1994). Words in dense neighbourhoods (e.g. *cat*) include more, high phonotactic probability sequences, whereas words in sparse neighbourhoods (e.g. *juice*) include more low phonotactic probability sequences. Given the inherent relationship between phonotactic probability and neighbourhood density, the term 'phonotactic probability/neighbourhood density' is used throughout the text, except when the two variables have been explicitly differentiated in prior research.

Children with TLD are sensitive to phonological regularities in their input language, reflected in their comprehension and production of higher frequency phonological forms and in their resultant lexical growth (Leonard *et al.* 1987, Storkel 2001, Storkel and Maekawa 2005, Zamuner *et al.* 2004). Specifically, they are more likely to add new words to their lexicons when they contain phonemes that they consistently produce, or attempt to produce in spontaneous speech, as compared with words that contain phonemes not in their productive vocabularies (Leonard *et al.* 1987). They are also more likely to produce phonemes in high phonotactic probability/neighbourhood density sound sequences correctly compared with low phonotactic probability/neighbourhood density sound sequences (Zamuner *et al.* 2004).

Young children with TLD clearly demonstrate sensitivity to the frequency of phonemes and phoneme sequences in the ambient language and make use of this information to facilitate lexical learning. In contrast, toddlers with early language delay may not take advantage of statistical properties of the language to which they are exposed (Stokes 2010). When examining neighbourhood density and word frequency, Stokes (2010) found that toddlers who were LT showed different patterns than their age-matched peers in their productive vocabularies.

Phonological representations in toddlers with TLD

Lexical acquisition appears to be influenced by the level of detail in the child's phonological representations (e.g. Metsala 1999). Initially, infants' phonological representations are hypothesized to be holistic, and then gradually become more detailed (e.g. Metsala 1999, Schwartz 1988, Storkel 2002). Several researchers have argued that increases in vocabulary size lead to this shift from holistic to segmental (e.g. Metsala 1999, Werker *et al.* 2002).

One methodology that has been used to infer the level of detail of phonological representations in young children is the preferential looking paradigm (PLP) (e.g. Swingley 2009, Werker *et al.* 2002). Young children hear correct and mispronunciations (e.g. *cat* and *zat*) of target words while seeing a picture of a cat and an unrelated referent. Equal looking time towards the target during mispronunciation and correct trials indicates underspecified phonological representations that lack phonetic detail. Greater looking time towards the target on correct trials than on mispronunciation trials suggests detailed phonological representations.

Two-year-old toddlers with TLD consistently respond to mispronunciations in familiar words that occur at onset or offset phonemes (Swingley 2009) and mispronunciations that involve one, two or three feature changes (e.g. Werker *et al.* 2002). Furthermore, 2-year-olds were found to be more sensitive to mispronunciations (for both onset and offset phonemes) of familiar words containing high phonotactic probability/neighbourhood density sequences

as compared with familiar words containing low phonotactic probability/neighbourhood density sequences (MacRoy-Higgins *et al.* 2012). However, toddlers with smaller vocabularies are less sensitive to mispronunciations of words than toddlers who have larger vocabularies, indicating that the detail of phonological representations is related to vocabulary size (Werker *et al.* 2002).

To summarize, in children with TLD an interaction between early lexicons and phonology has been well established (Storkel and Morrisette 2002). The child's experience with the distributional properties of sounds in words (i.e. phonotactics) clearly influences word learning by 3 years of age (e.g. Storkel 2001), and some studies indicate sensitivity to these properties as early as 2 years of age in children with TLD (e.g. Zamuner *et al.* 2004).

Purpose of the study

The goal of this investigation was to examine the influence of phonotactic probability/neighbourhood density on lexical acquisition in toddlers identified as LT, using a PLP paradigm to measure their sensitivity to mispronunciations of these words in order to infer the level of detail in their phonological representations. To date, no studies have examined this aspect of phonology on LT's ability to acquire new words. We expected the TLD toddlers to show an advantage for comprehending and producing words containing high as compared with low phonotactic probability/neighbourhood density forms, consistent with previous studies with TLD preschool children (e.g. Storkel 2001, Storkel and Maekawa 2005). They were also expected to show more detailed phonological representations for high as compared with low phonotactic probability/neighbourhood density sound sequences consistent with findings by MacRoy-Higgins *et al.* (2012). In contrast, we expected that the toddlers who were LT would not show similar sensitivities to the phonotactic structure of the target words in comprehension, production and detection of mispronunciations.

Method

Participants

Twenty-four toddlers, ranging in age from 21 to 25 months (mean = 23.2, SD = 1.3), participated in this study. Half of the toddlers (ten males, two females) were LT, as defined below, and the other half (ten males, two females) served as age- and gender-matched TLD controls. All participants came from monolingual English-speaking homes; they completed a series of standardized language tests to determine eligibility to participate in this study. The caregivers of the participants completed a case history form as well as a social-economic status (SES) questionnaire. Standardized tests and average scores are reported in table 1.

Toddlers identified as LT scored below the 15th percentile on the Communicative Development Inventory, 2nd Edition (CDI-2) and did not produce word combinations, according to parent report. As a group, LT standard scores were below average (< 1 SD from the mean) on the expressive portion of the Preschool Language Scale, 4th Edition (PLS-4). Standard scores on the Auditory Comprehension subtest of the PLS-4 and on the Bayley Mental Scale were within 1 SD for all LT participants. TLD controls scored within the average range on the Auditory Comprehension and Expressive Communication subtests of the PLS-4 and the Bayley Mental Scale. They scored at or above the 35th percentile on the CDI-2.

All LT and TLD participants passed hearing screenings. TLD participants were matched to LT participants in age, gender, SES and maternal education. Social economic status of the participant group ranged from middle to upper class. No participant (LT or TLD) had a history of hearing, cognitive, emotional and social disorders or delays as reported on the case history form.

Stimuli

Novel words—Twelve consonant–vowel–consonant (CVC) pseudo-word forms were created to serve as the experimental stimuli. A small, unfamiliar object (e.g. a small drain stopper) was chosen as the referent for each of the novel pseudo-words. Four additional unfamiliar objects were selected which were not given a label and were used as filler items during the PLP task. A digital picture of each of the objects was taken and used in the PLP. See appendix A for all objects, corresponding labels and filler objects.

Half (six) of the pseudo-words contained high phonotactic probability/neighbourhood density sequences and half (six) contained low phonotactic probability/neighbourhood density sequences. Phonotactic probability was calculated using a web-based phonotactic probability calculator (Vitevitch and Luce 2004) using both biphone and segment probabilities. High and low phonotactic probability/neighbourhood density pseudo-words contained three tense vowels, two lax vowels and one diphthong, and both contained a variety of consonant types (e.g. stops, fricatives, nasals, glides, etc.) in word initial and word final positions. Phonemes that are early, middle and late to develop (Shriberg *et al.* 1997) were comparable, with high phonotactic probability/neighbourhood density words containing four early phonemes, six middle phonemes and two late phonemes, and low phonotactic probability/neighbourhood density words containing three early phonemes, six middle phonemes and three late phonemes. Neighbourhood density was not controlled; pseudo-words containing high phonotactic probability sequences had more neighbours than words containing low phonotactic probability sequences; therefore, the stimuli represented high or low probability/density forms.

Two mispronunciations were created for each CVC pseudo-word to be used in the PLP. The phonological form of the mispronunciations differed from the target pseudo-words by one feature (manner or place of articulation) or by three features (manner, place and voicing). Additionally, the mispronunciations were in the onset or the offset of the word. The same variety of error types was used in a pilot study using real words, which showed that typically developing toddlers were sensitive to these mispronunciation errors (MacRoy-Higgins *et al.* 2012). Table 2 presents the pseudo-words and mispronunciations.

Video

A video of a native English speaker (the first author) was created and used during the word learning sessions to ensure that all participants heard the target words, produced in the same manner and the same number of times over the course of the training sessions.

The video consisted of the experimenter presenting the objects and their labels three times each, in the sentence-final position (e.g. *This is a /gig/*). All novel objects and filler objects were presented in the video; filler objects were not given a label, rather the experimenter produced a neutral sentence to describe the object (i.e. *This is another toy*).

Procedures

The pseudo-words were taught to the participants over ten training sessions (through video presentation and live presentation), followed by production and comprehension tasks and a PLP.

Training sessions—The 12 pseudo-words were presented to the participants over ten training sessions, similar to procedures used by Leonard *et al.* (1987). Each training session was audio and video recorded using a Sony Handycam DCR-DVD408 with an external Sony ECM-WH1R wireless microphone, which the experimenter wore. Training sessions were scheduled twice a week for 5 weeks in the toddler's home; the first author conducted

all training sessions. During each training session the toddler first watched the video of the researcher presenting the pseudo-words and objects on a portable DVD player. After the toddler watched the video, the experimenter randomly pulled the novel items from a large bag and produced the label for each pseudo-word to the toddlers in the sentence-final position (e.g. *Wow, here's a /gig/!*) and placed on the floor. The toddlers then manipulated and played with the objects for approximately 15 min. The experimenter produced the label for each novel object four additional times during each training session in the sentence-final position. The four filler items were present during the live training sessions; they were not given a label and the experimenter produced a neutral sentence (i.e. *This is another toy*) when referring to these objects. Each pseudo-word and its referent were presented to each toddler eight times during each training session; three productions were from the video, five productions were live (while the toddlers manipulated the objects). During the training sessions, participants were not prompted to point to the objects, imitate or produce the pseudo-words.

Comprehension and production testing—After the final training session, comprehension and production of the pseudo-words were tested. In previous studies examining word learning, word production is tested prior to word comprehension (e.g. Leonard *et al.* 1987). The procedures were modified where word comprehension was tested first, followed by word production because pilot testing revealed that the toddlers who were LT had difficulty with the production task. Presentation of the words in the comprehension task allowed the participants to hear the words produced by the experimenter first in order to facilitate production in the naming task.

In the comprehension task, practice trials with real objects (*spoon, cup, car* and *ball*) were used to familiarize the toddlers with the procedures. The four objects were placed on the floor; participants were asked to point to each object. The experimental trials began after the participant achieved 100% accuracy on the practice trials. This was achieved for all participants in both TLD and LT groups. The 12 experimental objects were presented randomly in groups of four; participants were asked to point to each object in the group after the prompt *Where's the ____?*

In the naming task, practice trials with real objects were used to familiarize them with the procedures; they were asked to name the *spoon, cup, car* and *ball*, after the prompt *What's this?* The experimental trials began after the participant named at least one object correctly. This was achieved for all participants. Toddlers were then asked to name each of the 12 experimental items after the prompt *What's this?*

As a final task, toddlers completed imitative practice trials with the real objects; they were asked to imitate the names of the *spoon, cup, car* and *ball*, after the prompt *This is a ____*. *Say ____*. The experimental trials began after the participant imitated at least one object correctly. This was achieved for all participants. Toddlers were asked to imitate each of the 12 experimental pseudo-words after the prompt *This is a ____*. *Say ____*. All tasks were audio and video recorded.

Preferential looking paradigm (PLP)—The PLP was completed during the last (11th) session in a sound-booth. The PLP was scheduled within 1 week of the tenth (home) training session. The 12 experimental words were split into two sets, each of which contained three high probability/density and three low probability/density pseudo-words. The participants were first familiarized with pseudo-words from either set 1 or set 2 (counterbalanced across the participants). The experimenter randomly selected the items from a bag and named the objects five times in the sentence-final position, while the toddlers manipulated the objects. Following familiarization, the participants completed the PLP task. After the completion of

the first half of the experiment (i.e. words from set 1 or set 2), the participants took a short break and then repeated the same procedures with the other set of six experimental pseudo-words. For the second set they received the familiarization procedure followed by the PLP task.

Each of the two sets of pseudo-words was presented via two blocks of 12 trials. Each block contained one correct and one mispronunciation of each word. Forty-eight trials were presented in total, with each word produced correctly twice and mispronounced twice. Within each block, trials were pseudo-randomized: correct and mispronunciations of the same target word were never presented consecutively, pictures of target objects appeared equally on the left and right monitors, the same picture did not appear consecutively, and a target novel word never followed or preceded its foil. Presentation of the two blocks per set was counterbalanced across participants.

For the PLP task, the toddlers were seated on their caregivers' lap in the centre of a sound booth. Two computer monitors were located in each corner of the room and a speaker and a Sony Digital 8 Video Camcorder were mounted between each of the monitors. The Speech Processing Software (SPS) (Tagliaferri and Schwartz 2007) was used to present the experimental trials and record scoring of looking behaviour. Before each trial, an auditory stimulus (animal sound) was presented via the loudspeaker to focus the participant's attention to the midline. Once this was achieved, the experimenter pressed a button to begin a trial. A trial consisted of the following events: two visual images (digital pictures) appeared on each of the monitors. The visual images remained for 3000 ms to allow the participant to look at the images, without auditory distraction. At 3000 ms, the auditory stimulus (correct or mispronunciation of the target word) was presented (e.g. *Where's the ___ ?*) via a speaker at approximately 70 dB SPL. The visual stimuli remained on the monitors for 3000 ms following the auditory stimulus. At the completion of a trial, the auditory distracter centred the participant to the midline and the experimenter triggered the advancement to the next trial. The video camera recorded the child's looking behaviour for each trial onto a computer hard drive, and behaviour was then scored using the SPS program by the experimenter at a later time. Throughout the experiment, the participant's caregiver listened to music via headphones to ensure that he/she did not influence the participant's looking behaviour.

Scoring

Each training session and the comprehension and production tasks were audio and video recorded. Comprehension of pseudo-words was scored while participants completed the comprehension (pointing) task after the final training session. The experimenter scored each response as correct (1) or incorrect (0). Word productions were coded off-line as correct (1): they correctly labelled the object; or incorrect (0): they were unable to label the object. In order to be considered a correct label, toddlers had to produce at least two of the three phonemes, consistent with Storkel (2001). Common (age-appropriate) articulation errors such as substituting a stop for a fricative or affricate, or substituting a front consonant for a back consonant were considered acceptable productions. Lastly, each participant completed an imitation task where they were given a model of each word and asked to repeat it. The percentage of consonants correct—revised (PCC-R; Shriberg *et al.* 1997) was calculated for all word productions to determine speech sound accuracy.

The participant's eye movements during the PLP were video recorded. The participant's looking preferences and durations at the images after hearing correct versus mispronunciations were scored off-line from the videos using SPS and left or right mouse clicks for direction of looking. The longest look difference (LLD) was calculated for each trial. It is the duration of the longest look at the target picture minus the duration of the

longest look at the distracter image. It was found to be the most reliable measure of looking time and accuracy during PLP tasks as compared with total looking time, where infants appeared to look at images in a more random manner as the trial proceeded (Shafer and Plunkett 1998). For each trial, LLD was calculated during the 3000 ms prior to the auditory stimulus and during the 3000 ms after the auditory stimulus.

Reliability

An additional experimenter, blind to the language status of the participants, scored 20% of the participants' responses for the production and preferential looking tasks in order to determine inter-judge reliability. For production data, PCC-R was obtained and per cent agreement was 100%. A Pearson product-moment correlation was used to estimate experimenter agreement for the coding of the preferential looking data. We required a correlation of at least 90% (0.90) for data to be considered reliable. This level of agreement was achieved for all participants (range = 0.91–0.99).

Data analysis

Three analyses were performed using repeated-measures analysis of variance (ANOVA), with group (LT versus TLD) as the between-subject variable. First, we examined word comprehension skills of high probability/density versus low probability/density words; the total number of high and low probability/density words that toddlers pointed to correctly served as the dependent variable. The second analysis examined word naming and speech sound accuracy of high probability/density versus low probability/density words. The total number of high and low probability/density words that were named in the task served as the dependent variable. The dependent variable for speech sound accuracy was the PCC-R (Shriberg *et al.* 1997), which was obtained from the word imitation condition. The final analysis examined looking durations at target images after hearing correct and mispronunciations of the high and low probability/density words during the PLP. The LLD served as the dependent variable. We also performed planned comparisons for the groups given the a priori prediction that the TLD group, but not the LT group, would demonstrate differences in sensitivity to mispronunciations as a function of phonotactic probabilities (Wilcox 1987). For all analyses, effect sizes were calculated and reported in η_p^2 .

Results

Word comprehension

All TLD participants completed all trials and eight of 12 LT participants completed all trials for the word comprehension task. Four LT participants completed some, but not all, of the trials, therefore for these participants partial data were analysed.

A mixed-model ANOVA with repeated measures examined the effect of Group (TLD versus LT) and Word Type (high probability/density versus low probability/density). A significant main effect of group $F(1, 22) = 10.74$, $p = 0.003$, $\eta_p^2 = 0.837$ was observed. The TLD participants performed better than the LT participants on the word comprehension task. No main effect of Word Type $F(1, 22) = 0.08$, $p = 0.67$ or interaction of Group $\times$ Word Type was observed $F(1, 22) = 0.00$, $p = 1.0$. No differences were observed in the performance of high and low probability/density words for TLD participants (High: mean = 5.2 correct (out of six), SD = 1.0, range = 4–6 correct; Low: mean = 5.1 correct (out of six), SD = 0.79, range = 4–6 correct) and LT participants (High: mean = 2.75 correct (out of six), SD = 2.6, range = 0–6 correct; Low: mean = 2.67 correct, SD = 2.35; range = 0–6 correct).

Word production

Naming—LT participants performed at floor on the naming task; no LT participant named a high or low probability/density word. A mixed-model ANOVA with repeated measures revealed a difference in the TLD participants' naming of high and low probability/density words $F(1, 11) = 10.185$, $p = 0.009$, $\eta_p^2 = 0.812$. TLD participants named more high probability/density words (mean = 4.1, SD = 2.0) as compared with low probability/density words (mean = 2.8, SD = 2.0).

Speech sound accuracy—Because LT participants performed at floor on the naming task, the word imitation task was used to examine speech sound production accuracy, measured using PCC-R (Shriberg *et al.* 1997). All toddlers with TLD completed this task. Despite having completed the criteria in the practice trials, three of the 12 LT toddlers did not complete any trials for the experimental task and were excluded from the following analysis.

A mixed-model ANOVA with repeated measures examined the effect of Group (TLD versus LT) and Word Type (high probability/density versus low probability/density). Main effects of Group $F(1, 19) = 51.8$, $p < 0.00001$, $\eta_p^2 = 0.702$, of Word Type $F(1, 19) = 31.0$, $p < 0.00001$, $\eta_p^2 = 0.584$ and a significant Group $\times$ Word Type interaction $F(1, 19) = 8.4$, $p = 0.0008$, $\eta_p^2 = 0.276$ were observed. Post-hoc Tukey HSD testing revealed that the TLD group more accurately produced high probability/density words as compared with low probability/density words ($p = 0.0002$) (High: 88.3%, SD = 10.4%; Low: 54.6%, SD = 15.9%). There was no significant difference between the LT production accuracy of high probability/density and low probability/density words ($p > 0.05$) (High: 39.5%, SD = 19.1%; Low: 28.5%, SD = 20.5%). The TLD group showed higher PCC-R scores than the LT group for both high probability/density words ($p = 0.0002$) and low probability/density words ($p = 0.0002$). Thus, the interaction was the result of the LT group showing no significant difference in accuracy between the high and low probability/density words.

Toddlers with TLD showed higher performance on high than low probability/density words for both labelling and speech sound accuracy measures. In contrast, the LT group showed no difference in performance between the high and low probability/density words. Overall, the TLD group performed better than the LT group on these measures.

Preferential looking paradigm (PLP)

Comparison of pre-auditory stimulus versus post-auditory stimulus trials—

Comparisons were made between the LLD before and after the sentences were presented. A mixed-model ANOVA with repeated measures examined the effect of Group (TLD versus LT) and Looking Response (pre-auditory stimulus versus post-auditory stimulus). A main effect of Looking Response was observed $F(1, 22) = 41.574$, $p = 0.000001$, $\eta_p^2 = 0.653$. The LLD before the auditory stimulus was close to zero for LT and TLD groups, indicating random looking at both images before the sentence. The LLD after the auditory stimulus was longer than the LLD pre-auditory stimulus and similar in LT and TLD toddlers. Table 3 displays these values.

No differences were found between groups $F(1, 22) = 0.236$, $p = 0.63$ and no Group $\times$ Looking Response interaction was observed $F(1, 22) = 0.023$, $p = 0.88$.

Comparison of high probability/density versus low probability/density words

—The target word in the auditory stimulus was either high probability/density or low probability/density, and was either correct or a mispronunciation (e.g. correct /*gig*/ versus mispronunciation /*dig*/). A mixed-model ANOVA with repeated measures examined the

effect of Group (TLD versus LT), Word Condition (correct versus mispronunciation) and Word Type (high probability/density versus low probability/density). A main effect of Word Condition was observed $F(1, 22) = 10.587, p = 0.004, \eta_p^2 = 0.325$. Both TLD and LT groups had a greater LLD after hearing a correctly produced form, as compared with the LLD after hearing a mispronunciation. All TLD participants showed this pattern. Seven of the 12 toddlers who were LT demonstrated this pattern (longer LLD for correctly produced forms as compared with mispronunciations). No main effect of Group $F(1, 22) = 0.618, p = 0.44$, or Word Type $F(1, 22) = 0.310, p = 0.58$ was observed. No Group $\times$ Word Condition, Group $\times$ Word Type, Word Condition $\times$ Word Type, or Group $\times$ Word Condition $\times$ Word Type interaction was observed ($p > 0.05$) for all interactions.

Given the a priori prediction that the TLD group, but not the LT group, would demonstrate differences in sensitivity to mispronunciations as a function of phonotactic probability, we had planned within-group comparisons (Wilcox 1987).

Within-group comparisons: TLD participants: A repeated-measures ANOVA was performed with Word Condition (correct versus mispronunciation) and Word Type (high probability/density versus low probability/density) as the within-subject variables. A main effect of word condition was observed where the LLD was greater for correct as compared with mispronunciations $F(1, 11) = 8.94, p = 0.012, \eta_p^2 = 0.448$. A Word Condition $\times$ Word Type interaction was significant, $F(1, 11) = 4.625, p = 0.05, \eta_p^2 = 0.296$. Post-hoc Tukey HSD revealed a significantly greater LLD to the correct than the mispronunciation form in the high probability/density condition ($p = 0.02$). There was no significant difference in the LLD for correct and mispronunciations in the low probability/density condition. See table 3 and the TLD portion of figure 1.

Within-group comparisons: LT participants: A repeated-measures ANOVA was performed with Word Condition (correct versus mispronunciation) and Word Type (high probability/density versus low probability/density) as the within-subject variables. No main effect of Word Condition or Word Type was observed ($p > 0.05$). No Word Condition $\times$ Word Type interaction was observed ($p > 0.05$). See table 3 and the LT portion of figure 1.

Summary of PLP results: Both TLD and LT toddlers looked longer at the target image after hearing the words produced correctly versus mispronunciations. The TLD toddlers showed significant differences in phonological perception of high versus low probability/density words. In contrast, the LT toddlers showed no difference between these conditions.

Discussion

The experiments revealed that, as predicted, toddlers with TLD show sensitivity to phonological regularities in the production and detection of mispronunciations in newly learned words. The results suggest that some toddlers who are LT do not or cannot take advantage of the statistical properties of their native language to aid in word learning. Thus, we have some support for the suggestion that an underlying weakness in phonological representations may contribute to poor word learning in this population.

Word learning

Toddlers who were LT demonstrated poorer word learning on both comprehension and production tasks as compared with their peers with TLD. The results are consistent with a previous study, which found that toddlers who were LT were not efficient in adding new vocabulary to their receptive repertoire during a fast mapping task (Ellis Weismer and Evans 2002). Similarly, the LT in this study scored more poorly on the comprehension task as

compared with their TLD peers; however, we did observe some toddlers who were LT to perform similarly to their peers.

On the production tasks, toddlers with TLD also demonstrated better word learning than toddlers who were LT. All toddlers with TLD, but none who was LT labelled some objects when prompted. In some cases, the failure to label the objects spontaneously may be due to poor learning of the names, as demonstrated in the comprehension task. However, some toddlers who were LT comprehended at least half of the words. Thus, failure to label the objects cannot be attributed to poor comprehension in these toddlers.

The results related to phonotactic probability/neighbourhood density suggest that the nature of the phonological representation may have contributed to the poor word learning. The TLD toddlers showed an advantage for high probability/density sequences both for spontaneous naming of words and in speech sound accuracy in the imitation task. In contrast, the toddlers who were LT showed no advantage for high over low probability/density words. In addition, LT's overall precision in consonant production (PCC-R) was lower than that for controls, which is consistent with other studies that indicate delayed articulation and phonological development (e.g. Williams and Elbert 2003). The pattern of findings cannot be attributable solely to phoneme complexity and delays in acquiring more complex phonemes. Both high and low probability/density words were composed of phonemes that are early, middle and late to develop (Shriberg *et al.* 1997) and a variety of consonant types (e.g. stops, fricatives, nasals, glides). The TLD toddlers showed greater production accuracy for high probability/density words, which was predicted based on previous studies (e.g. Zamuner *et al.* 2004). The equally poor performance by the late talking toddlers on the high and low probability/density words might reflect insensitivity to phonotactic probability. However, it could also be a function of small phonological inventories. Specifically, the toddlers who were LT may not have been able to make use of the statistical properties of the words because they were not yet able to produce many of the phonemes.

Sensitivity to mispronunciations and phonological representations

The PLP paradigm examined toddlers' sensitivity to mispronunciations of the newly learned words. Only the toddlers with TLD showed a clear advantage for high over low probability/density words. We predicted that the TLD toddlers would show more detailed phonological representations for high probability/density words as compared with low probability/density words based on the previous study in which toddlers with TLD showed this pattern in familiar, one-syllable words (MacRoy-Higgins *et al.* 2012). In the current study, all TLD toddlers were sensitive to phonological mismatches of high probability/density words, but they did not look differentially in response to correct versus mispronunciations of low probability/density words. These results suggest that phonological representations may be less detailed for low probability/density forms than for high probability/density forms in toddlers with TLD. Thus, with sufficient experience with high probability/density sequences, toddlers with TLD are sensitive to mispronunciations and thus, appear to be capable of establishing detailed phonological representations for novel words containing these forms.

Unlike their peers with TLD, late talking toddlers were not sensitive to mispronunciations for words with either high or low probability/density sequences. In fact they exhibited a looking pattern for both high and low probability/density words that was more similar to the pattern found for low probability/density sequences in the toddlers with TLD. This finding suggests that some toddlers who are LT have overall weak phonological representations that lack detail for both high and low probability/density words. It is possible that the LT toddlers' insensitivity to mispronunciations is related to lexical factors. LT had fewer than

50 words in the expressive vocabularies; therefore, their representations may be stored in a holistic manner, influencing their ability to detect mispronunciations. It is also possible that once the LT acquire a certain vocabulary size (e.g. 100 words) they are then able to recognize language regularities.

Relationship between comprehension and production

The TLD toddlers show evidence of a bidirectional system (Gershkoff-Stowe and Hahn 2007) where expressive vocabulary growth seems to facilitate infants' phonological perception skills, which in turn facilitates future word learning, consistent with a connectionist model (Storkel and Morrisette 2002). The toddlers with TLD had expressive vocabularies of over 300 words; therefore, they had a great deal of experience producing words with high probability/density sounds and sound sequences. Repeated productions of words with high probability/density sequences may help to establish detailed phonological representations of these forms, and help to facilitate access and production of these forms. Likewise, a detailed phonological perceptual system seems to facilitate word learning and production. The TLD toddlers in this investigation showed more detailed phonological representations of high probability/density forms; and also named more high probability/density words and produced consonants in high probability/density words with higher accuracy than low probability/density words.

Storkel (2001, 2009) found that young children who are still developing their productive phonology system are able to use phonological cues to influence lexical learning. The influence of phonological characteristics on lexical learning is established early in development and continues to influence lexical representations in toddlers aged 1;4–2;6 years (Storkel 2009). Unlike their peers, the toddlers who were LT in this study did not show evidence of an interaction between phonology and lexical acquisition measured by the phonological production and preferential looking tasks. The underlying deficit in toddlers who are LT could be an early inability to detect regularities in the phonological system of the language to which that they are exposed. Recent findings from Stokes (2010) are consistent with this suggestion. As compared with their TLD peers, toddlers who were LT showed a different pattern of neighbourhood density and word frequency in their productive vocabularies. Stokes concluded that LT extract the statistical properties of language in a manner that is different than their peers.

This investigation is the first to show differences in the detail of phonological representations in toddlers who are LT. As compared with their TLD peers, toddlers who are LT may require more exposures in order to be able to store phonological forms with sufficient detail needed to comprehend and produce words containing these forms. Increased practise in producing words may help toddlers who are LT to establish detailed phonological representations and therefore facilitate new word acquisition, similar to toddlers with TLD.

Future directions

As a group, LT toddlers performed more poorly on all experimental tasks; however, in comprehension and in the PLP paradigm, the performance of some LT toddlers resembled their peers. A question that arises from these findings is whether the poor performers on comprehension and detection of mispronunciations will continue to show poor language abilities, and be diagnosed with SLI, and whether the children with better comprehension and detection of mispronunciations will be those who resemble their typically developing peers. We could not include a typically developing, vocabulary-matched group in the study because they might have been too young to perform the tasks. Therefore, we do not know whether the phonological representations of the LT group were delayed and similar to younger, TLD toddlers, or whether they are atypical. It would be fruitful to complete a

follow-up study examining whether preschool children who were identified as LT show better performance with high compared with low probability/density sequences. These results may help to determine if toddlers who are LT are merely delayed, or whether they continue to show no sensitivity to statistical properties of phonology and the lexicon.

Conclusion

LT appear to be delayed in both areas of expressive vocabulary and phonological representations. Converging evidence from comprehension, production and recognition tasks suggest that the detail of phonological forms in toddlers who are LT is not similar to their peers. Limited practise producing high probability/density sequences may contribute to differences in the underlying phonological systems and difficulty comprehending and producing new words in toddlers who are LT. However, it is unclear at this time whether the lexical learning skills of late-talking children resemble younger children with TLD or whether these skills are atypical.

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What this paper adds

Some toddlers demonstrate an early language delay of unknown origin. These toddlers, who are late talkers, have difficulty adding new words to their vocabulary and also show delays in phonological development. Typically developing toddlers use statistical properties of language such as phonotactic probability to aid in lexical acquisition. In contrast, toddlers who are late talkers do not seem to use statistical properties of language when learning new words, which may contribute to their early language delay.

Figure 1. Longest look difference (LLD) values for high and low probability/density words, produced correctly and incorrectly (mispronunciation) for typically developing (TLD) and late talking (LT) participants. Vertical bars denote $\pm$ standard errors.

Table 1
Participant information, including mean age (SD) (months and days) and scores (SD) on language and cognitive measures

	Age (months;days)	PLS-4, AC ^a	PLS-4, EC ^b	CDI-2 (percentile)	CDI-2 (number of words)	BSID-3 ^c
TLD						
Mean (SD)	23;4 (1;27)	110 (8)	109 (9)	63 (16)	345 (121)	109 (7)
LT						
Mean (SD)	23;00 (1;26)	101 (12)	84 (10)	10 (5)	41 (5)	103 (7)

Notes: PLS-4 = Preschool Language Scale, Fourth Edition (Zimmerman *et al.* 2002); CDI-2 = MacArthur–Bates Communicative Development Inventories, Second Edition, Words and Sentences (Fenson *et al.* 2007); and BSID-3 = Bayley Scales of Infant Development, Third Edition, Mental Scale (Bayley 2006).

^a Auditory Comprehension standard score.
^b Expressive Communication standard score.
^c Mental Scale standard score.

Table 2

High and low phonotactic probability/neighbourhood density non-word stimuli and mispronunciations given in the International Phonetics Alphabet

Non-word stimuli	Initial mispronunciation	Type	Final mispronunciation	Type
<i>High phonotactic probability/density</i>				
/sed/	/ted/	M	/sez/	M
/kʌv/	/pʌv/	P	/kʌθ/	P
/kof/	/pof/	P	/koʃ/	P
/lep/	/nep/	M	/lev/	MPV
/væd/	/kæd/	MPV	/væz/	M
/part/	/zart/	MPV	/paim/	MPV
<i>Low phonotactic probability/density</i>				
/zetʃ/	/detʃ/	M	/zeʃ/	M
/gig/	/dig/	P	/gib/	P
/fuð/	/nuð/	MPV	/fup/	MPV
/tov/	/sov/	P	/toz/	M
/θɒb/	/sɒb/	P	/θɔm/	M
/dorɪf/	/tʃɔɪf/	MPV	/dɔɪl/	MPV

Note: M, manner of articulation; P, place of articulation; and V, voicing.

Table 3

Mean (SD) LLD values (ms) for typical language developing (TLD) and late talking (LT) participants for each preferential looking paradigm (PLP) condition

Condition		TLD	LT
Pre-auditory		-7 (401)	25 (178)
Post-auditory		582 (374)	641 (295)
Correct	All conditions	825 (492)	849 (494)
Mispronunciation	All conditions	389 (415)	431 (500)
Correct	High phonotactic probability/density	917 (563)	826 (528)
	Low phonotactic probability/density	697 (609)	872 (664)
Mispronunciation	High phonotactic probability/density	50 (778)	509 (557)
	Low phonotactic probability/density	534 (425)	435 (788)

Appendix A

Objects corresponding to high and low phonotactic probability/density pseudo-words. Filler objects were not given a label

High probability/ density pseudo- words	Object	Low probability/ density pseudo-words	Object	Filler objects
/sed/		/zeɪ/
/kʌv/		/gɪg/
/kɒf/		/tʌð/
/e/p		/tʌv/

High probability/ density pseudo- words	Object	Low probability/ density pseudo-o-words	Object	Filler objects
/væd/		/ðɒb/
/palt/		/dɒlf/