The effect of homonymy on learning correctly articulated versus misarticulated words

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ARTICLE

The effect of homonymy on learning correctly articulated versus misarticulated words

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Abstract

Purpose: The goal of the current study was to examine the effect of homonymy (learning a second meaning for a *known* word form vs. learning a novel meaning and *novel* word form) and articulation accuracy (IN vs. OUT sounds) on word learning by preschool children. An added goal was to determine whether word frequency altered the effect of homonymy on word learning.

Method: Twenty-nine 3- to 4-year-old children were taught homonyms and novel words. Stimuli further varied in whether homonymy was present in both the adult input and the child's output (as for IN sounds) versus present only in the child's output (as for OUT sounds).

Results: For IN sounds, children learned homonyms more rapidly than novel words. Moreover, the homonym advantage was modulated by word frequency, such that children learned a new meaning for a high frequency word more accurately than they learned a new meaning for a low frequency word. In contrast, for OUT sounds, there was no evidence that homonymy influenced learning.

Conclusions: Homonymy in the adult input facilitates word learning by preschool children, whereas homonymy in the child's output alone does not. This effect is captured in a usage-based model of phonology and the lexicon.

Introduction

Usage-based theories of language acquisition assume that mental representations of language are gradually learned through experience listening to and producing the target language (Bybee, 2001; Munson, Edwards, & Beckman, 2012; Pierrehumbert, 2001). Pierrehumbert (2001) offers an exemplar model of a usage-based theory of phonology and the lexicon. In this model, each abstract linguistic category is represented as a cloud of experienced tokens of the category stored in long-term memory. For example, as shown in Panel A of Figure 1, individual tokens of a particular category, such as the sound sequence in the word "wait," are grouped in memory. That is, each experience of hearing the word "wait," namely input tokens (underlined in Figure 1), and each experience of producing the word "wait," namely output tokens (plain font in Figure 1), are stored in memory. This group of similar perceptual and motor experiences can be thought of as the *lexical representation* for the word "wait." Although Figure 1 depicts these experiences as phoneme units, Pierrehumbert's model actually relies on acoustic representations of tokens. Phonemes are used in Figure 1 only to condense the illustration. Each lexical representation also is associated with a *semantic representation*, which consists of the meaning or referent exemplars. Note that for simplicity, the semantic representations in Figure 1 are depicted as definitions, rather than the posited cloud of experiences. In terms of the *phonological representation*, it is hypothesized that the exemplar cloud for a given *sound* is the "union" of the portion of the exemplar cloud of all the *words* containing the specific sound, with the portion of the exemplar cloud being that which corresponds to the specific sound. This is depicted in Figure 1 Panel A (rectangles) for the shared vowel and coda in "wait" and "rate," although in reality many more words (including non-neighbors) would contribute exemplars to the phonological representation of a particular sound. In this model, it is clear that phonology and the lexicon are presumed to be tightly coupled, with both emerging from the same set of experiences listening to and producing language.

Correct Articulation

During the preschool years, children are building their lexicon and their phonology in parallel through this set of experiences listening and producing language. In some cases, children correctly produce the words they hear. That is, the child's output matches the adult input. This is shown in Panel A of Figure 1, where the underlined adult input tokens are represented as similar to the child's output tokens, shown in plain font. It is important to note that this match of input and output could be broadly similar without exact matching of acoustic or phonetic detail. This represents the hypothesized scenario for correctly articulated sounds and words.

A second scenario for correctly articulated sounds and words is shown in Panel B of Figure 1. This panel illustrates homonymy. *Homonymy* occurs when one sound sequence has two distinct meanings (e.g., *bank* can refer to a 'financial institution' or 'the edge of land by a river'). As seen in Panel B of Figure 1, the instances of hearing or producing the sound sequence "bank" create one lexical representation (or cloud of exemplars) associated with two distinct semantic representations. In contrast, *non-homonyms* occur when one word form has one meaning (e.g., *wait* meaning 'delay action'). As shown in Panel A of Figure 1, this results in one lexical representation associated with one semantic representation. Note that for correctly articulated words, homonymy and lack of homonymy are present in both the adult input and the child's output.

Studies evaluating the role of homonymy in learning correctly articulated words show contrasting results. On the one hand, some studies show that children learn non-homonyms, specifically learning a novel meaning and novel word form, faster than they learn homonyms, specifically learning the second meaning of a known word form. This homonym disadvantage has been attributed to competition between the first (i.e., known) and second (i.e., new) meaning of the homonym and/or to a preference for one-to-one mappings between lexical and semantic representations (Doherty, 2004; Mazzocco, 1997; Mazzocco, Myers, Thompson, & Desai, 2003). Importantly, the homonym disadvantage has been shown only in studies that rely on receptive tasks, which arguably place greater demands on semantic than on lexical representations, and only in tasks where both the known and new meaning of the homonym are available as response choices. Thus, competition between the two meanings may occur during testing, rather than during learning. In contrast, other studies suggest that children learn homonyms faster than they learn non-homonyms (Storkel & Maekawa, 2005). This homonym advantage was shown in an expressive task, which arguably places greater demand on lexical than on semantic representations. In this case, the homonym advantage is attributed to differences in the amount of learning required. In the case of a non-homonym, the exemplars of the sound sequence and the meaning must be clustered to create both a new lexical and semantic representation. In comparison, the exemplars of the sound sequence for a homonym can be added to the existing lexical representation and only a new semantic representation needs to be created, thereby speeding learning (Storkel & Maekawa, 2005). Only one study has demonstrated a homonym advantage (Storkel & Maekawa, 2005). Thus, one goal of this study was to replicate the previous finding of a homonym advantage in an expressive task with new stimuli and new participants. A second goal was to extend the previous findings by investigating the impact of word frequency and misarticulation on the homonym effect.

Word frequency

Word frequency refers to the number of times a word occurs in a language, with numerous psycholinguistic and learning studies demonstrating an advantage for high frequency words over low frequency words (e.g., German & Newman, 2004; McGregor, Sheng, & Ball, 2007; Metsala, 1997; Rice, Oetting, Marquis, Bode, & Pae, 1994). In usage-based theories, frequency plays a central and critical role because frequency determines the number of exemplars of a particular category (Bybee, 2001; Pierrehumbert, 2001). Specifically, a high frequency word will have more exemplar tokens in memory than a low frequency word, and this influences processing. In terms of the effect of homonymy, word frequency could influence learning of a second meaning of a known word form. In particular, a low frequency word with few exemplars in memory may not be that different from a novel word with no exemplars in memory. It is possible that many exemplars in memory may be required to trigger a homonym advantage (or disadvantage). The prior study of correctly articulated homonyms provided preliminary support for this hypothesis (Storkel & Maekawa, 2005). However, this previous analysis was exploratory with only a few low frequency words being tested. The current study specifically manipulates word frequency during stimuli selection to better address the issue of whether word frequency modulates the difference in learning homonyms versus non-homonyms.

Misarticulation

The current study also seeks to address the more complex case where the child's output does not match the adult input, namely a misarticulated sound and word (e.g., Edwards, Fourakis, Beckman, & Fox, 1999; Priestly, 1980; Velleman, 1988). An example is shown in Figure 2. The adult input is /reɪt/ for the target word "rate" but the child's output is [weɪt]. Note also that the child's output creates homonymy, at least in the output, with the correctly articulated word "wait." That is, the child's output of [weɪt] for "wait" is perceptually indistinguishable to the adult listener from the child's output of [weɪt] for "rate." How this homonymy in the output affects the mental representation of the sound and the word is open to debate. Two possible scenarios are illustrated in Figure 2.

As shown in Panel A of Figure 2, the mismatch between input and output and the resulting homonymy in the output may have minimal impact on the representations formed (c.f., Dinnsen, 2002; Dinnsen, O'Connor, & Gierut, 2001; Storkel, 2004a). Specifically, the phonological representation differentiates target /r/ from target /w/ and the lexical representation differentiate target "wait" from target "rate." This pattern is consistent with evidence of covert contrasts (e.g., Gierut & Dinnsen, 1986; Locke, 1979; Maxwell & Weismer, 1982; Tyler, Edwards, & Saxman, 1990; Weismer, Dinnsen, & Elbert, 1981). When a covert contrast is present, acoustic measures of production show that a child consistently produces a sound differently when it is being used as a substitute (e.g., [w] as a substitute for target /r/ in /reɪt/) than when it is being used target appropriately (e.g., [w] for target /w/ in /weɪt/). Pierrehumbert's (2001) exemplar model may be particularly well-suited for capturing covert contrasts because the phonological and lexical representations carve out categories in the perceptual phonetic space. Thus, the child's representations need not carve out categories along the exact same dimensions as in the adult target, consistent with other findings in the developmental literature (e.g., Nittrouer, 1993; Nittrouer & Miller, 1997; Nittrouer & Studdert-Kennedy, 1987; Smith & Goffman, 1998). Moreover, the child's category boundaries can shift with development to become more adult-like. Notably, the hypothesized representations are consistent with the adult input, which differentiates the two target sounds and words. Moreover, the representations are non-homonymous even though there is (perceived) homonymy in the child's output. In this way, the correctly articulated non-homonym in Figure 1 Panel A and this misarticulated word in Figure 2 Panel A are similar.

On the other hand, the representations could mimic the homonymy observed in the output (e.g., Macken, 1980; Maxwell, 1984; Vihman, 1982). Panel B of Figure 2 illustrates no differentiation within the phonological or lexical representation. This scenario would be consistent with findings that children sometimes fail to perceive sounds they misarticulate or show no evidence of a covert contrast (Edwards, et al., 1999; Edwards, Fox, & Rogers, 2002; Rvachew & Jamieson, 1989; Rvachew, Ohberg, Grawburg, & Heyding, 2003). This hypothesized representation is consistent with the child's output, which collapses the two target sounds and words, leading to homonymy. Note that this representation is similar to that of a correctly articulated homonym, shown in Figure 1 Panel B.

These two possible representations of misarticulated sounds and words illustrate the extremes. It is possible that the representation could be a hybrid of the adult input and the child's output. This issue will be returned to in the discussion. For now, the two extreme scenarios offer clearly different predictions of how homonymy in the child's output could impact learning of misarticulated words. In the first illustrated case (i.e., Figure 2 Panel A), the homonymy is isolated to the child's output. The hypothesized phonological and lexical representations show no evidence of homonymy. In this case, learning of misarticulated words that result in (perceived) homonymy in the child's output should be similar to learning misarticulated words that do not result in homonymy in the child's output (or the adult input), namely non-homonyms. In contrast, in the second illustrated case (i.e., Figure 2 Panel B), the homonymy is present in the child's output and in the phonological and lexical representations. In this case, learning of misarticulated words that result in homonymy in the child's output should differ from learning misarticulated words that do not result in homonymy in the child's output (i.e., non-homonyms). Here, it is predicted that the effect of homonymy in the child's output would be similar to the effect of homonymy in the adult input. Recall that correctly articulated homonyms facilitate learning relative to correctly articulated non-homonyms in expressive tasks. Thus, homonymy in the child's output should facilitate learning relative to non-homonyms (cf., Velleman & Vihman, 2002; Vihman, 1981 for findings of this effect in very young children). The current study addresses these predictions by fully crossing misarticulation (IN vs. OUT sounds) with homonymy (learning a second meaning for a *known* word form vs. learning a novel meaning and *novel* word form).

Method

Participants

Twenty-nine 3- to 4-year-old (*M* = 3 years; 9 months, *SD* = 0; 5, range 3; 0 – 4; 9; 45% males, 55% females) children participated. Based on a parent questionnaire, developmental and medical histories were unremarkable. Children passed a hearing screening (ASHA, 1997) and exhibited normal phonological development (Goldman & Fristoe, 2000) with standard scores within a standard deviation of the mean (*M* = 98, *SD* = 5, range = 89 – 106). Children also exhibited normal vocabulary development (Brownell, 2000a, 2000b) with standard scores within a standard deviation of the mean for either receptive (*M* = 109, *SD* = 9, range = 91 - 134) and/or expressive (*M* = 105, *SD* = 13, range = 78 – 133) vocabulary.

One of the independent variables was misarticulation, operationally defined as whether a child correctly articulated a target sound (i.e., IN) or misarticulated a target sound (i.e., OUT). To classify sounds as IN versus OUT, children were administered a *phonological probe* adapted from Gierut (2008) to test production of potential IN (/m n p b t k/) and OUT sounds (/v θ □ t□ l r/). Potential IN sounds consisted of early acquired unmarked sounds, specifically nasals and stops, that typically developing preschool children were most likely to articulate with high accuracy based on developmental norms (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). In complement, potential OUT sounds consisted of late acquired marked sounds, specifically fricatives and liquids, that typically developing preschool children were likely to articulate with low accuracy based on norms (Smit, et al., 1990). For each sound, production was elicited in picture naming of 10 words, 5 targeting initial position and 5 targeting final position, to determine overall accuracy in production of each sound as well as accuracy by position. To participate, children were required to (1) correctly articulate at least two of the target IN sounds and (2) misarticulate at least two of the target OUT sounds by producing a specified substitute in word-initial position. Table 1 shows the selected IN and OUT sounds for the children. Note that other measures of phonology, such as perceptual discrimination or fine-grained articulatory measures, were not obtained.

For each child, one stop and one nasal were selected as IN sounds (see appendix). For these IN sounds, children were 100% accurate producing the sound in word-initial position and 99% accurate (*SD* = 5%, range = 80% - 100%) in word-final position. Based on a detailed phonological analysis, the selected IN sounds were determined to be mastered, showing no evidence of positional or inventory constraints. Turning to OUT sounds, one liquid and one fricative were selected as OUT sounds for 28 of the 29 children (see appendix). For the remaining child, two fricatives were selected because the two liquids failed to meet criteria for OUT sounds. For the OUT sounds, children were 4% accurate producing the sounds in word-initial position (*SD* = 8%, range = 0% - 20%) and 12% accurate in word-final position (*SD* = 31%, range = 0% - 100%). Positional constraints (i.e., sound produced incorrectly in word-initial but correctly in word-final position) were noted for 12% of selected OUT sounds, and inventory constraints (i.e., sound produced incorrectly in all word positions) were noted for 88% of selected OUT sounds. Moreover, children produced the specified substitute for OUT sounds in 97% (*SD* = 9%, range 60% - 100%) of their word-initial errors, indicating a relatively consistent substitute for the OUT sounds. On-line supplemental materials provide further characterization of each child's IN and OUT sounds. Taken together, there was some minor variability in production accuracy for OUT sounds. This variability was accounted for in the statistical analysis procedure by incorporating random effects for participants and items.

Lastly, production of the word-final consonants used in the stimuli was assessed using a probe similar to the IN/OUT phonological probe. Specifically, production of /m n p b t d k g/ was elicited in word-final position, with two words targeting each sound. To participate, children were required to correctly produce these word-final consonants.

For the phonological probe (i.e., IN/OUT and word-final consonants) and norm-referenced articulation test (Goldman & Fristoe, 2000), point-to-point inter-judge transcription reliability (i.e., proportion of agreements) was computed for 21% of participants with mean reliability of 96% (*SD* = 3%, range 91-99%).

Stimuli

Stimuli were selected from a pool of high phonotactic probability and high neighborhood density consonant-vowel-consonant (CVC) sequences. High probability and high density CVCs were used because previous research suggests that these sequences are learned more readily than low probability/low density (Storkel, 2001, 2003, 2004a; Storkel & Rogers, 2000). Phonotactic probability and neighborhood density were computed using a 20,000 word adult corpus (Nusbaum, Pisoni, & Davis, 1984). Previous work suggests that comparable values are obtained when using a child corpus (Storkel & Hoover, 2010). Two measures of phonotactic probability were computed: positional segment sum and biphone sum (Storkel, 2004b). Positional segment sum was computed by summing the positional segment frequency of each sound in the CVC. Positional segment frequency is the sum of the log frequency of all the words in the adult corpus containing a given sound in a given word position divided by the sum of the log frequency of all the words in the corpus containing any sound in the given word position. Computation of the biphone sum used the same method except the sound pair was the unit of analysis rather than an individual sound. Neighborhood density was computed by counting the words in the adult corpus that differed from a given CVC by a one phoneme substitution, deletion or addition in any word position. High phonotactic probability was defined as a minimum positional segment sum of 0.11 and a minimum biphone sum of 0.0026. High neighborhood density was defined as a minimum of 10 neighbors. Table 2 shows the phonotactic probability and neighborhood density of the selected stimuli.

For OUT sounds, the probability and density of the child's misarticulated pronunciation also was computed (e.g., probability/density of child's misarticulated pronunciation of [wæt] for target /læt/) and was required to meet the same probability and density minima as the target pronunciation. It is important to note that the positional segment frequency of the first sound differed with IN sounds being more frequent than OUT sounds, $F\,(1, 74) = 52.76$, $p < 0.001$, $\eta_p^2 = 0.42$. Thus, it was not possible to perfectly match the IN and OUT conditions on positional segment sum $F\,(1, 74) = 4.16$, $p = 0.045$, $\eta_p^2 = 0.05$, but the IN and OUT conditions were well matched on biphone sum, $F\,(1, 74) = 0.22$, $p = 0.64$, $\eta_p^2 = 0.003$, and density $F\,(1, 74) = 0.27$, $p = 0.27$, $\eta_p^2 = 0.02$.

A second independent variable was homonymy (learning a second meaning for a *known* word form vs. learning a novel meaning and *novel* word form). For each sound selected, two known and two novel CVCs were selected from the high probability/density pool. The selected stimuli are shown in the appendix. For IN sounds, known CVCs were those that appeared in a compiled corpus of words spoken by children (Storkel & Hoover, 2010), whereas novel CVCs were those that did not appear in the child corpus. For example, for IN sound /m/, 'mud' and 'mom' were selected as known, and /moʊb/ and /maʊn/ were selected as novel.

When selecting known CVCs, a third independent variable was manipulated: word frequency (low vs. high). Word frequency was taken from the same compiled corpus of words spoken by children (Storkel & Hoover, 2010). For each IN sound, one known CVC was low frequency and the other known CVC was high frequency. For example, for the known /m/ words, 'mud' is low frequency with a log frequency of 1.57 (raw frequency of 37 occurrences), whereas 'mom' is high frequency with a log frequency of 2.64 (raw frequency of 434 occurrences). The log frequency for the low frequency known IN stimuli was 0.96 (SD = 0.68, range 0-1.68) and for the high frequency known IN stimuli was 2.37 (SD = 0.50, range 1.84-3.79). Note that the low and high frequency known IN stimuli did not differ in segment sum, $F\ (1, 23) = 0.61$, $p = 0.45$, $\eta_p^2 = 0.03$, biphone sum, $F\ (1, 23) = 0.16$, $p = 0.70$, $\eta_p^2 = 0.007$, or density, $F\ (1, 23) = 0.41$, $p = 0.53$, $\eta_p^2 = 0.02$.

Stimuli selection for OUT sounds followed a similar procedure except that the status of both the target pronunciation and the child's misarticulated pronunciation had to be considered. As with IN sounds, two known and two novel CVCs were selected for each OUT sound. Known CVCs were those with target pronunciations that did not occur in the corpus but misarticulated pronunciations that did occur in the corpus. For example, target /vʌn/ (misarticulated as [bʌn]/'bun') and target /vɛd/ (misarticulated as [bɛd]/'bed') were selected as known stimuli for OUT sound /v/ ([b] substitute) because 'bun' and 'bed' occurred in the child corpus. In contrast, novel CVCs were those with target pronunciations and misarticulated pronunciations that did not occur in the child corpus. For example, target /væp/ (misarticulated as [bæp]) and target /voʊk/ (misarticulated as [boʊk]) were selected as novel stimuli for OUT sound /v/ ([b] substitute). Refer to the appendix for a full list of stimuli. As with IN sounds, the word frequency of the known stimuli was manipulated such that one stimulus was low frequency and the other high. Thus, for /v/, /vʌn/ ('bun') was low frequency with a log frequency of 0.95 for 'bun' (raw frequency of 9 occurrences), whereas /vɛd/ ('bed') was high frequency with a log frequency of 2.95 for 'bed' (raw frequency of 894 occurrences). The log frequency for the low frequency known OUT stimuli was 1.16 (*SD* = 0.59, range 0-1.79) and for the high frequency known OUT stimuli was 2.38 (*SD* = 0.56, range 1.87-3.38). Note that the low and high frequency known OUT stimuli did not differ in segment sum, $F(1, 13) = 0.54$, $p = 0.48$, $\eta_p^2 = 0.04$, biphone sum, $F(1, 13) = 1.43$, $p = 0.25$, $\eta_p^2 = 0.10$, or density, $F(1, 13) = 0.13$, $p = 0.73$, $\eta_p^2 = 0.01$. In addition, the values for low and high frequency are comparable across the IN and OUT stimuli, $F(1, 38) = 0.17$, $p = 0.68$, $\eta_p^2 = 0.004$.

Two potential differences between the known IN and OUT stimuli warrants comment. First, the majority (i.e., 72%) of known IN stimuli had primary noun meanings, whereas only a minority (i.e., 40%) of known OUT stimuli had primary noun meanings. As will be detailed in the procedures section, the second meaning taught during this study was always a noun meaning. There is only a small literature on the influence of grammatical class on recognition or learning of homonyms by children and adults. However, the available literature suggests that a mismatch in grammatical class, which is more prevalent in the known OUT stimuli, would be more likely to facilitate recognition or learning than a match in grammatical class, which is more prevalent in the known IN stimuli (Casenhiser, 2005; Mirman, Strauss, Dixon, & Magnuson, 2010). Thus, this asymmetry would favor finding a significant effect of homonymy for OUT stimuli rather than for IN stimuli. Second, age-of-acquisition ratings were examined for known IN versus OUT stimuli (Bird, Franklin, & Howard, 2001; Gilhooly & Logie, 1980). Although age-of-acquisition ratings could only be found for 60% of the stimuli, the values were comparable across the IN (M = 2.83, SD = 0.68, range 1.97 – 4.42) and OUT known stimuli (M = 2.89, SD = 1.15, range 1.69 – 5.25), F (1, 22) = 0.02, p = 0.88, η_p^2 = 0.001. Taken together, word frequency and age-of-acquisition of known words was similar across the IN and OUT stimuli, and all known stimuli occurred in a corpus of words spoken by children similar in age to the participants (Storkel & Hoover, 2010). Thus, the known IN stimuli appear comparable in familiarity to the known OUT stimuli.

The 16 CVCs selected for each set of IN/OUT sounds (see appendix) were paired with a previously developed set of novel objects (Storkel, 2004a; Storkel & Maekawa, 2005). Briefly, four novel objects were selected from each of four semantic categories (i.e., candy machines, pets, horns, toys), yielding a total of 16 novel objects. CVCs were paired with the novel objects such that each misarticulation x homonymy condition was paired with an object from each semantic category.

Procedures

The 16 CVC-object pairs for each set of IN/OUT sounds were divided into two training sets with two CVCs from each misarticulation x homonymy condition in each set. Training and testing for each set occurred on separate days. All experimental tasks were administered on laptop computer via DirectRT experimental control software (Jarvis, 2002). A session began with baseline testing in a picture-naming task. Each novel-object picture was presented and children were encouraged to guess its name. Picture naming was chosen because previous studies of homonym learning show that expressive tasks lead to a homonym advantage, likely due to expressive tasks placing greater demands on lexical than on semantic representations (Storkel & Maekawa, 2005). Training then was initiated with presentation of the CVC-object pairs in a game format. Each training trial presented a picture of a novel object centered on the computer screen. The child then heard the semantic category and the target CVC in the following exposure sentences: "Everybody likes *semantic category*. This is a *CVC*. You can play (with) a *CVC*. Say *CVC*. That's a *CVC*. We are going to play a game. Find the *CVC*. That's the *CVC*. Say *CVC*. Remember, that's a *CVC*." Note that the exposure script provided eight exposures (i.e., adult input) to the target CVC along with two production attempts (i.e., child output) without feedback. Thus, the ratio of adult input tokens to child output tokens was 4:1 in a given training segment. The 'find' prompt initiated game play. Game play always involved finding a hard copy picture card that matched the picture on the computer screen. After training was completed for the first item, remaining items were administered in turn following the same procedures. Upon completion of training, picture naming was re-tested. This cycle of training and testing was repeated four times in a session. Retention of the first training set was tested one-week later, yielding a total of five test points during/following training. The second training set then was trained and tested following the same procedures.

Scoring

Picture-naming responses were audio-recorded, phonemically transcribed and scored. A response was scored as correct if it contained all three target sounds in the correct sequence. For

OUT sounds, production of the specified substitute for the target OUT sound was considered correct (e.g., [bɛd] for target /vɛd/ would be three of three phonemes correct for target /v/ with [b] substitute). Only 4 of 29 participants produced an OUT sound accurately (i.e., with the intended target). Each of these four participants only produced one particular nonword accurately, and these productions were scored as correct. In all other cases, children produced the intended substitute for OUT sounds, and these productions also were scored as correct. Data were analyzed excluding these accurate productions with no subsequent change in the statistical outcome or interpretation. Thus, the presented results include the data from all children, even those few children who accurately produced an OUT sound in one nonword.

Point-to-point inter-judge transcription reliability (i.e., proportion of agreements) was computed for 21% of participants with mean reliability of 98% (*SD* = 1%, range 96-99%). Scoring reliability (i.e., proportion of agreements) was computed for 21% of participants with mean reliability of 100% (*SD* = 0.4%, range 99-100%).

Analysis Approach

The data were analyzed using multilevel modeling. Multilevel modeling (MLM), also called mixed effects modeling, hierarchical linear modeling, or random coefficient modeling, is gaining increasing recognition as an advantageous method for handling dependencies in repeated measures data (Cnaan, Laird, & Slasor, 1997; Gueorguieva & Krystal, 2004; Hoffman & Rovine, 2007; Misangyi, LePine, Algina, & Goeddeke, 2006; Nezlek, Schroder-Abe, & Schutz, 2006; H. Quene & van den Bergh, 2004). MLM is seen as a more flexible alternative to repeated measures ANOVA because problematic assumptions (e.g., sphericity) are avoided, and incomplete data (i.e., unbalanced data, missing data) are easily accommodated. Moreover, models with random intercepts can be employed to account for between participant and/or between item differences in measured outcomes while also estimating the effects of the independent variables of interest, which may be modeled as fixed or random effects. To illustrate, in the case of a random intercept for participants, the random intercept captures each participant's deviation from the grand mean. Conceptually, this can be thought of as allowing each participant to have their own individual intercept, accounting for individual variation in initial performance. At the same time, the effect of an independent variable, such as time, can be examined. If the effect of the independent variable is modeled as a fixed effect, then the effect of the variable is constrained to be the same across participants and/or items. In the previous example, participants may differ in initial performance (i.e., random effect of participants) but the effect of time may be (approximately) the same for each participant (i.e., significant fixed effect of time).

The present analysis used a cross-classified random effects multilevel model, which is becoming a favored method for analyzing psycholinguistic data (cf., Baayen, Davidson, & Bates, 2008; Locker, Hoffman, & Bovaird, 2007; H. Quene & van den Bergh, 2008). The cross-classified random effects model serves as the preferred solution to the language-as-fixed-effect fallacy noted by Clark (1973) because this approach models the random effects of participants and items in the same analysis (rather than using separate participant and items ANOVAs). This allows for a "truer" modeling of variances as it is no longer necessary to collapse across participants or items. In terms of the data structure of the current study, children were assigned to different versions of the experiment based on their misarticulation patterns (see appendix). That is, participants and items (i.e., CVCs to be learned) are nested within version, whereas participants and items are said to be crossed at the same level (i.e., not nested within one another). In addition, participants and items were measured repeatedly (i.e., baseline + 5 tests of interest). Thus, the overall structure is repeated measures at different tests (level 1), nested in participants (level 2) and items (level 2), nested in version (level 3).

The dependent variable for the present analysis is accuracy (i.e., correct or incorrect), which is a binary dependent variable. Thus, a logistic MLM is required. Logistic MLM is computationally more complex than traditional MLM. Specifically, in the binary distribution, the variance is calculated as a function of the mean; therefore, level 1 error variance is not estimated and is assumed to be fixed at $\pi^2/3$ (Snijders & Bosker, 1999). When random effects are crossed, generated fit statistics are based on pseudo-likelihoods and should not be used to compare models, even if such models are nested (SAS, 2008).

Results

As is typical in MLM, the covariance structure was first explored to determine the need of using a multilevel model. Random effects for version, participants, items, and test were separately added to the model and a likelihood ratio test was performed to assess significance. Only significant effects were retained in subsequent models. The random effects of participants and items were significant, $\chi^2(1) = 49.85$, $p < .001$ for participants; $\chi^2(1) = 304.71$, $p < .001$ for items. Calculated ICCs for participants and items were .16 and .41, respectively. Therefore, about 16% of the total variance was between participants and 41% was between items.

Fixed effects of test (test 1, 2, 3, 4, 5: retention), misarticulation (IN, OUT), homonymy (known, novel) and their interactions were sequentially added to the model and significance was assessed by *F* tests. Again, significant effects were retained and non-significant effects were removed from the final model. Odds ratios were computed as a measure of effect size when comparing two conditions. The odds ratio is interpreted as how much more likely a correct response is in the first condition than in the second condition. For example, an odds ratio of 2.4

would indicate that a correct response is 2.4 times more likely in the first condition than the second condition. The final model included random effects of participants and items (as previously described) and fixed effects of test, misarticulation, homonymy, and the interaction of misarticulation and homonymy.

The fixed effect of test was significant, F (4, 2164) = 3.96, $p < .01$. Follow-up comparisons with Bonferroni correction revealed accuracy at test 4 (M = .13, SE = .02) was significantly greater than accuracy at test 1 (M = .07, SE = .01), adjusted p = .01, OR = 2.45. Likewise, accuracy at test 4 was significantly greater than at test 5: retention (M = .07, SE = .01), adjusted p = .01, OR = 2.44. Thus, naming performance improved during exposure (i.e., from test 1 to test 4) but then declined across the no exposure delay (i.e., from test 4 to test 5: retention). Turning to the main variables of interest for the study goals, the fixed effect of misarticulation was significant, F (1, 2164) = 6.05, p = .01, OR = 2.73. Specifically, children were significantly more accurate at recalling IN words (M = .14, SE = .02) than OUT words (M = .05, SE = .01). Additionally, the fixed effect of homonymy was significant, F (1, 2164) = 14.20, $p < .001$, OR = 4.66. That is, accuracy was significantly greater for known word forms (M = .15, SE = .02) than for novel word forms (M = .03, SE = .01).

These main effects were qualified by a significant interaction of misarticulation (IN vs. OUT) and homonymy (known vs. novel), F (1, 2164) = 5.74, p = .02. It appears that this interaction is driven by an effect of homonymy (novel vs. known) for IN sounds but not for OUT sounds. In particular, for IN sounds, there was a significant effect of homonymy, F (1, 2164) = 20.63, $p < .001$, OR = 12.4. As shown in Figure 3, accuracy for IN known words (M = .24, SE = .03) was greater than accuracy for IN novel words (M = .03, SE = .01). In contrast, for OUT sounds, the effect of homonymy was not significant and the odds ratio was small, F (1, 2164) =

.87, p = .35, OR = 1.8. As shown in Figure 3, accuracy for OUT known words (M = .06, SE = .02) was similar to accuracy for OUT novel words (M = .04, SE = .01). Recall that homonymy was defined differently for IN than for OUT sounds. In particular, classification of known versus novel for IN sounds was based on the adult input, whereas classification of known versus novel for OUT sounds was based on the child's output. Thus, homonymy based on the adult input (as in IN sounds) significantly affected learning, whereas homonymy based on the child's output (as in OUT sounds) did not significantly affect learning.

Recall that for known words, word frequency varied with half of the words being low frequency and half being high frequency. Because the effect of homonymy was significant for IN sounds but not OUT sounds, the frequency effect was only examined for IN sounds. To accomplish this, the same covariance structure as in the prior analyses was used (i.e. crossed random effects), and fixed effects of test and frequency (low vs. high) were included in the model. The frequency effect was significant, F (1, 520) = 6.56, p = .01, OR = 5.8. As shown in Figure 4, children were significantly more accurate when learning a second meaning for a high frequency word (M = .34, SE = .06) than when learning a second meaning for a low frequency word (M = .15, SE = .05). Importantly, both high and low frequency words were significantly more accurate than novel words, F (1, 1068) = 5.91, p = .02 OR = 4.88 for low frequency; F (1, 1068) = 27.36, p <.01, OR = 26.48 for high frequency (see Figure 4). Thus, both types of known words were learned significantly better than novel words but within known words, high frequency words were learned significantly better than low.

Discussion

Results showed an interaction between articulation and homonymy. When homonymy was based on the adult input (i.e., correctly articulated IN sounds), children learned homonyms more accurately than non-homonyms. Moreover, this homonym advantage was modulated by word frequency, such that homonyms with high frequency word forms were learned more accurately than homonyms with low frequency word forms. In contrast, when homonymy was based on the child's output (i.e., misarticulated OUT sounds), children achieved similar accuracy in learning these "output" homonyms (e.g., /vɛd/ misarticulated as [bɛd]) and non-homonyms (e.g., /væp/ misarticulated as [bæp]). The theoretical implications of each finding will be discussed, in turn.

Correct Articulation

For correctly articulated words (i.e., IN sounds), the finding of a homonym advantage in word learning by preschool children replicated the findings of a prior study (Storkel & Maekawa, 2005). As such, the current results provide further support for the hypothesis that learning a homonym differs from learning a non-homonym in the amount of learning required (see Figure 1). Specifically, learning a homonym presumably requires that the encountered exemplars of the sound sequence be added to the existing lexical representation and that the encountered exemplars of the new meaning be added to memory but also clustered to create a new semantic representation (i.e., a cluster of exemplars in a usage model). In contrast, learning a non-homonym requires storing the exemplars in memory and creating *both* a lexical and semantic cluster of those exemplars. These results also are consistent with findings from studies of infant word learning. Specifically, when infants are exposed to a sound sequence in the absence of meaning (i.e., segmentation task) they perform better in a word learning task (i.e., sound sequence paired with meaning) than when they have not been exposed to the sound sequence (Graf Estes, Evans, Alibali, & Saffran, 2007). In this instance, children likely are able to store exemplars of the sound sequence during the first task (i.e., segmentation task) and perhaps create a lexical representation. This experience with the sound sequence of a word thus creates a lexical foundation for subsequent learning in a manner similar to learning a second meaning of a homonym. Importantly, these results are inconsistent with prior claims that children are slow to learn words that violate a one-to-one correspondence between lexical and semantic representations, requiring more cues or evidence to overcome this preference for unique mappings (e.g., Markman, 1989; Slobin, 1973).

Word Frequency

The results extended those of the prior study (Storkel & Maekawa, 2005) by providing clearer evidence that this advantage of homonymy is further modulated by word frequency. The influence of word frequency is consistent with usage-based accounts of language acquisition where frequency is intrinsic to the model (Bybee, 2001; Pierrehumbert, 2001). Specifically, frequency represents the number of exemplars of a given category. This, in turn, affects processing because categories with more exemplars have higher resting activation levels than those with fewer exemplars, making access to those categories with many exemplars faster (Pierrehumbert, 2001). Thus, a high frequency word will have more exemplars of the sound sequence (and meaning) in memory than a low frequency word, and high frequency words will be accessed more rapidly than low frequency words. The current results expand this account by demonstrating that the number of exemplars in memory influences learning. Specifically, when learning a new meaning for a high frequency word form, the stored exemplars will be accessed more rapidly than when learning a new meaning for a low frequency word form. This effect on access to stored exemplars could facilitate other aspects of learning. In addition, learning a new meaning for a high frequency word may involve storage of the new semantic exemplars and creation of a semantic representation only; whereas learning a new meaning for a low frequency word may involve this same semantic process but also greater updating or refining of the existing lexical representation. This is consistent with the concept of entrenchment in usage models, where well practiced categories become more stable and more resistant to change (Bybee, 2001; Pierrehumbert, 2001). Taken together, the findings suggest that gradient differences in the number of exemplars (i.e., many vs. few vs. none) subtly change the amount of learning required, and this influences how quickly or accurately a word is learned.

Misarticulation

When homonymy was based on the child's output (i.e., OUT sounds), there was no advantage for homonyms over non-homonyms. This finding is consistent with the phonological and lexical representations portrayed in Figure 2 Panel A. That is, the phonological and lexical representations differentiate the two sounds and the two words. In this way, the amount of learning is similar to the case where the child's output does not result in homonymy. In both cases, the child must store the new exemplars and create both a lexical and semantic representation. Note also that this pattern of results is consistent with the expected representations when a child exhibits a covert contrast (e.g., Gierut & Dinnsen, 1986; Locke, 1979; Maxwell & Weismer, 1982; Tyler, et al., 1990; Weismer, et al., 1981). This raises the possibility that the children in this study may all have covert contrasts for the selected OUT sounds, a possibility that cannot be tested in the current data set due to a lack of acoustic data.

However, an alternative phonological and lexical representation scenario requires consideration. Recall that Figure 2 illustrates two extreme scenarios for phonological and lexical representations, with Panel A being consistent with the adult input and Panel B being consistent with the child's output. It is possible that alternative scenarios representing a hybrid of the input and output also could account for the data. For example, the phonological representation may not differentiate the perceived substituted sound (e.g., /w/) and the intended target sound (e.g., /r/), as in the phonological representation shown in Panel B of Figure 2, but the lexical representation could differentiate target "wait" from target "rate," as shown in Panel A of Figure 2. It's possible that this type of hybrid scenario could arise because the child might rely on semantic information or other cues (e.g., syntactic) to discern that target "wait" and "rate" are distinct lexical items but these cues may not be sufficient to drive differentiation of the phonological representation. In this alternative scenario, it is likely that a covert contrast would not be present because no contrast is present in the phonological representation. To further explore these two different scenarios (and possibly others), additional information, such as detailed perceptual or production data, is needed to better understand the child's phonological and lexical representations. Importantly, it would be useful to address these issues in a similar sized or larger group of children and with a greater variety of OUT sounds to elucidate whether one of these two scenarios (or some alternative) occurs uniformly for all typically developing children or for all OUT sounds or whether these scenarios vary by child or by sound. Information such as this would be helpful in understanding variation in phonological and lexical development in typically developing children.

Three caveats are important to note because they potentially guide future research efforts. First, the training biased the adult input over the child output and this could have influenced the results. Recall that during training the ratio of adult input to child output (via direct imitation) was four-to-one. Thus, there were four times as many exemplars of the adult input than the child output. This could have facilitated the child's ability to create distinct phonological and lexical representations, as depicted in Figure 2 Panel A. It's possible that a different picture would emerge if the ratio of adult input to child output were reversed. In this situation, there would be many more exemplars of the child's output than the adult input, which could lead to a pattern of learning that would be more consistent with the representations depicted in Figure 2 Panel B. This manipulation of the ratio of input and output during training could be combined with further manipulation of the input and output relationship. Specifically, the current method pitted homonymy in the output alone (e.g., /vɛd/ misarticulated as [bɛd]) with non-homonymy in the input and output (e.g., /væp/ misarticulated as [bæp]). Comparing homonymy in the output alone (e.g., /vɛd/ misarticulated as [bɛd], "bed") to homonymy in the input alone (e.g., /vaɪn/, "vine" misarticulated as [baɪn]), along with manipulation of the input and output ratio during training, could further elucidate the role of input and output in forming phonological and lexical representations.

Turning to the second caveat, there was not a great deal of variability in the phonological profiles of the OUT sounds for this group of typically developing children. That is, the majority of OUT sounds were characterized by inventory constraints and consistent substitutes (refer to supplemental material). However, these phonological profiles were based on somewhat limited data (i.e., adult transcription of word productions, rather than additional acoustic measures of production and/or measures of perception). It is possible that different conclusions would be supported if a wider range of misarticulation profiles, including profiles based on both input and output measures of phonology, had been tested. Investigation of children with phonological disorders might be particularly helpful in this regard. Children with phonological disorders, by definition, misarticulate a wider array of sounds than typically developing children. Thus, it might be possible to identify OUT sounds with different profiles (e.g., positional vs. inventory constraint) within the same child and determine how these different profiles impact word learning. Likewise, investigation of children with phonological disorders would serve as an important comparison to data from typically developing children. As outlined for typically developing children, it is possible that the status of phonological and lexical representations could vary across children with phonological disorders or across OUT sounds within the same child with a phonological disorder. Understanding this type of variation within children with phonological disorders and comparing it to that of typically developing children would provide a fuller picture of similarities and differences in phonological and lexical development across both groups of children.

Moving to the final caveat, the theoretical account rests on a null result, namely the lack of an effect of homonymy for OUT sounds, and performance in both OUT conditions was rather poor (i.e., means ranged from .02 to .09 across test points). It's possible that additional training that raised accuracy to a higher level could reveal a difference between novel and known words in the OUT condition. However, it is interesting that the effect of word familiarity did emerge in the IN condition with the limited training provided in this study. Thus, it appears that learning was poor in all conditions that involved learning new lexical representations (i.e., IN novel, OUT novel, OUT known) and was better in the condition that involved learning a second meaning of a known word form (i.e., IN known). This pattern further supports the account but doesn't rule out the possibility that a difference could emerge between OUT novel and OUT known words under different conditions (e.g., increased accuracy).

Conclusion

Results replicated previous work demonstrating a homonym advantage when homonymy is present in the adult input and child output (i.e., correctly articulated words, Storkel &

Maekawa, 2005). Moreover, the results extended that prior work by providing evidence that characteristics of the known word form, specifically word frequency, affected the size of the homonym advantage. In contrast, when homonymy was present only in the child's output (i.e., misarticulated words), no benefit was observed. All three effects were accounted for within a usage-based model of phonology and the lexicon, which suggests new directions for future research.

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Appendix: Stimuli

IN	IN Known (log frequency)	IN Novel	OUT (subst)	OUT Known (log frequency)	OUT Novel	Percent of Kids
/n/	‘nip’ (0.00), ‘knock’ (2.10)	/noʊk/, /num/	/θ/ ([f])	/θɛd/ (‘fed’ 1.49), /θæt/ (‘fat’ 1.88)	/θʌt/ ([fʌt]), /θɪd/ ([fɪd])	38%
/p/	‘pad’ (1.23), ‘pot’ (1.84)	/pʌd/, /pɪb/	/r/ ([w])	/rɛb/ (‘web’ 1.30), /rɪn/ (‘win’ 2.32)	/rɑp/ ([wɑp]), /run/ ([wun])	
/m/	‘met’ (1.46), ‘mean’ (2.44)	/maɪd/, /mʌn/	/ʃ/ ([s])	/ʃoʊk/ (‘soak’ 0.00), /ʃæd/ (‘sad’ 2.03)	/ʃɪg/ ([sɪg]), /ʃɛk/ ([sɛk])	21%
/b/	‘bum’ (0.00), ‘bike’ (2.08)	/beɪm/, /boʊg/	/r/ ([w])	/rɛb/ (‘web’ 1.30), /rɪn/ (‘win’ 2.32)	/rɑp/ ([wɑp]), /run/ ([wun])	
/m/	‘mud’ (1.57), ‘mom’ (2.64)	/moʊb/, /maʊn/	/v/ ([b])	/vʌn/ (‘bun’ 0.95), /vɛd/ (‘bed’ 2.95)	/væp/ ([bæp]), /voʊk/ ([boʊk])	21%
/k/	‘cop’ (1.34), ‘kid’ (2.30)	/keɪb/, /kaɪd/	/r/ ([w])	/rɛb/ (‘web’ 1.30), /rɪn/ (‘win’ 2.32)	/rɑp/ ([wɑp]), /run/ ([wun])	
/n/	‘note’ (1.68), ‘nine’ (2.11)	/næm/, /nɑn/	/θ/ ([f])	/θɛd/ (‘fed’ 1.49), /θaɪn/ (‘fine’ 1.87)	/θʌt/ ([fʌt]), /θɪd/ ([fɪd])	7%
/t/	‘tin’ (1.26), ‘tape’ (2.14)	/toʊb/, /tɛm/	/l/ ([w])	/lɑd/ (‘wad’ 1.79), /loʊk/ (‘woke’ 2.00)	/lɛm/ ([wɛm]), læt/ ([wæt])	
/n/	‘nip’ (0.00), ‘nine’ (2.11)	/nʌk/, /næd/	/θ/ ([s])	/θæk/ (‘sack’ 1.57), /θɛd/ (‘said’ 3.38)	/θʌt/ ([sʌt]), /θɪg/ ([sɪg])	7%
/k/	‘kite’ (1.60), ‘can’ (3.79)	/kʌg/, /koʊg/	/r/ ([w])	/rɛb/ (‘web’ 1.30), /rɪn/ (‘win’ 2.32)	/rɑp/ ([wɑp]), /run/ ([wun])	
/m/	‘mop’ (0.30), ‘men’ (2.70)	/mʌb/, /moʊk/	/ʃ/ ([s])	/ʃaɪt/ (‘sight’ 1.04), /ʃun/ (‘soon’ 2.65)	/ʃɪg/ ([sɪg]), /ʃɛk/ ([sɛk])	3%
/b/	‘bake’ (1.11), ‘bite’ (2.00)	/boʊg/, /bæp/	/l/ ([w])	/lɑd/ (‘wad’ 1.79), /loʊk/ (‘woke’ 2.00)	/lɛm/ ([wɛm]), læt/ ([wæt])	

/p/	‘pad’ (1.23), ‘pig’ (2.08)	/pʌd/, /peɪg/	/θ/ ([f])	/θɛd/ (‘fed’ 1.49), /θæt/ (‘fat’ 1.88)	/θʌt/ ([fʌt]), /θɪd/ ([fɪd])	3%
/b/	‘beak’ (0.00), ‘boat’ (2.62)	/bʌp/, /bɪm/	/ʃ/ ([s])	/ʃoʊk/ (‘soak’ 0.00), /ʃun/ (‘soon’ 2.65)	/ʃɪg/ ([sɪg]), /ʃɛk/ ([sɛk])	

Note that log frequency 0.00 corresponds to a raw frequency of 1 occurrence of the target word in a sample of 1,028,417 words spoken by kindergarten and first grade children; log frequency 1.00 to 10, log frequency 2.00 to 100, and log frequency 3.00 to 1,000.

Table 1

Selected IN and OUT sounds (with substitute in parentheses) for participating children.

IN	IN	OUT	OUT	Percent of Children
/n/	/p/	/θ/ ([f])	/r/ ([w])	38%
/m/	/b/	/ʃ/ ([s])	/r/ ([w])	21%
/m/	/k/	/v/ ([b])	/r/ ([w])	21%
/n/	/t/	/θ/ ([f])	/l/ ([w])	7%
/n/	/k/	/θ/ ([s])	/r/ ([w])	7%
/m/	/b/	/ʃ/ ([s])	/l/ ([w])	3%
/p/	/b/	/θ/ ([f])	/ʃ/ ([s])	3%

Table 2

Phonological and lexical characteristics of the stimuli based on the adult target pronunciation versus child misarticulated pronunciation.

		Adult Target Pronunciation				Child's Misarticulated Pronunciation			
		Positional Segment Sum	Biphone Sum	Density	Log Frequency	Positional Segment Sum	Biphone Sum	Density	Log Frequency
IN Known	M	0.17	0.009	19	1.70	Same as Adult Target Pronunciation (i.e., not misarticulated)			
	(SD)	(0.04)	(0.006)	(5)	(0.92)				
	range	0.11-0.27	0.003-0.027	11-27	0-3.79				
IN Novel		0.15	0.008	16	N/A	Same as Adult Target Pronunciation (i.e., not misarticulated)			
		(0.03)	(0.010)	(5)					
		0.10-0.21	0.003-0.055	10-28					
OUT Known		0.14	0.006	16	N/A	0.18	0.007	20	1.81
		(0.03)	(0.006)	(6)		(0.04)	(0.003)	(5)	(0.84)
		0.11-0.24	0.003-0.027	10-29		0.12-0.24	0.003-0.014	6-26	0-3.38
OUT Novel		0.14	0.005	15	N/A	0.17	0.008	18	N/A
		(0.02)	(0.003)	(6)		(0.04)	(0.004)	(5)	
		0.11-0.18	0.003-0.010	11-32		0.12-0.23	0.003-0.016	11-26	

Figure Captions

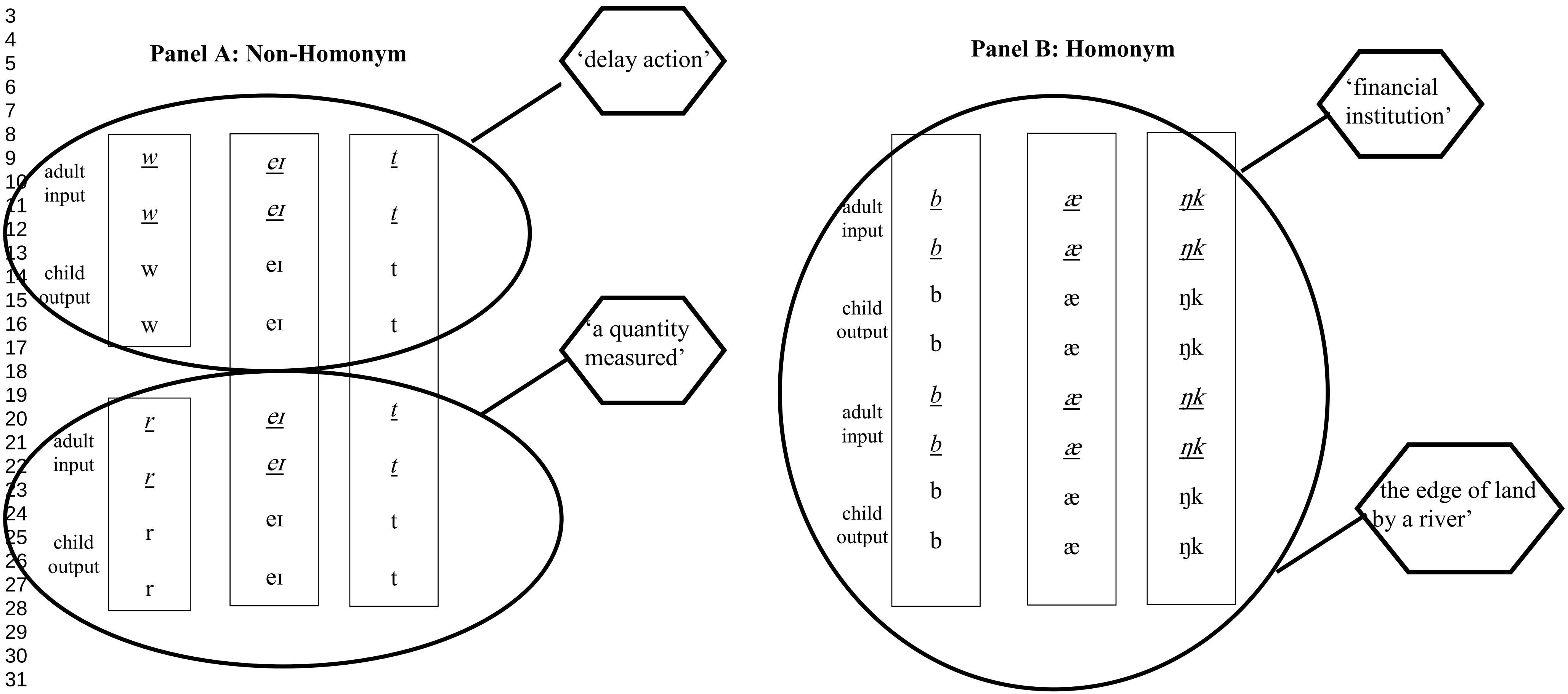
Figure 1. Possible phonological (rectangles), lexical (ovals), and semantic (hexagon) representations for: Panel A - a correctly articulated non-homonym ("wait" and "rate"); Panel B - a correctly articulated homonym ("bank"). Italics and underlining indicate sounds and words that were heard (i.e., adult input), whereas those in plain font without underlining indicate sounds and words that were produced by the child (i.e., child's output). Associated meaning is indicated by a line to a definition (hexagon).

Figure 2. Possible phonological (rectangles), lexical (ovals), and semantic (hexagon) representations for "rate" and "wait" for a child who produces both as [weɪt]. Italics and underlining indicate sounds and words that were heard (i.e., adult input), whereas those in plain font without underlining indicate sounds and words that were produced by the child (i.e., child's output). Associated meaning is indicated by a line to a definition (hexagon).

Figure 3. Mean proportion correct at each test for IN Known (open bar), IN Novel (dark bar), OUT Known (dotted bar), and OUT Novel (striped bar). Error bars indicate standard errors.

Figure 4. Mean proportion correct at each test for IN Known – High Frequency (open bar), IN Known – Low Frequency (light bar), and IN Novel (dark bar). Error bars indicate standard errors.

Figure 1.


Panel A: Non-Homonym
'delay action'
adult input
child output
w
w
w
w
eɪ
eɪ
eɪ
eɪ
t
t
t
t
'a quantity measured'
adult input
child output
r
r
r
r
eɪ
eɪ
eɪ
eɪ
t
t
t
t
Panel B: Homonym
'financial institution'
adult input
child output
adult input
child output
b
b
b
b
b
b
b
b
æ
æ
æ
æ
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ŋk
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'the edge of land by a river'

Figure 2.

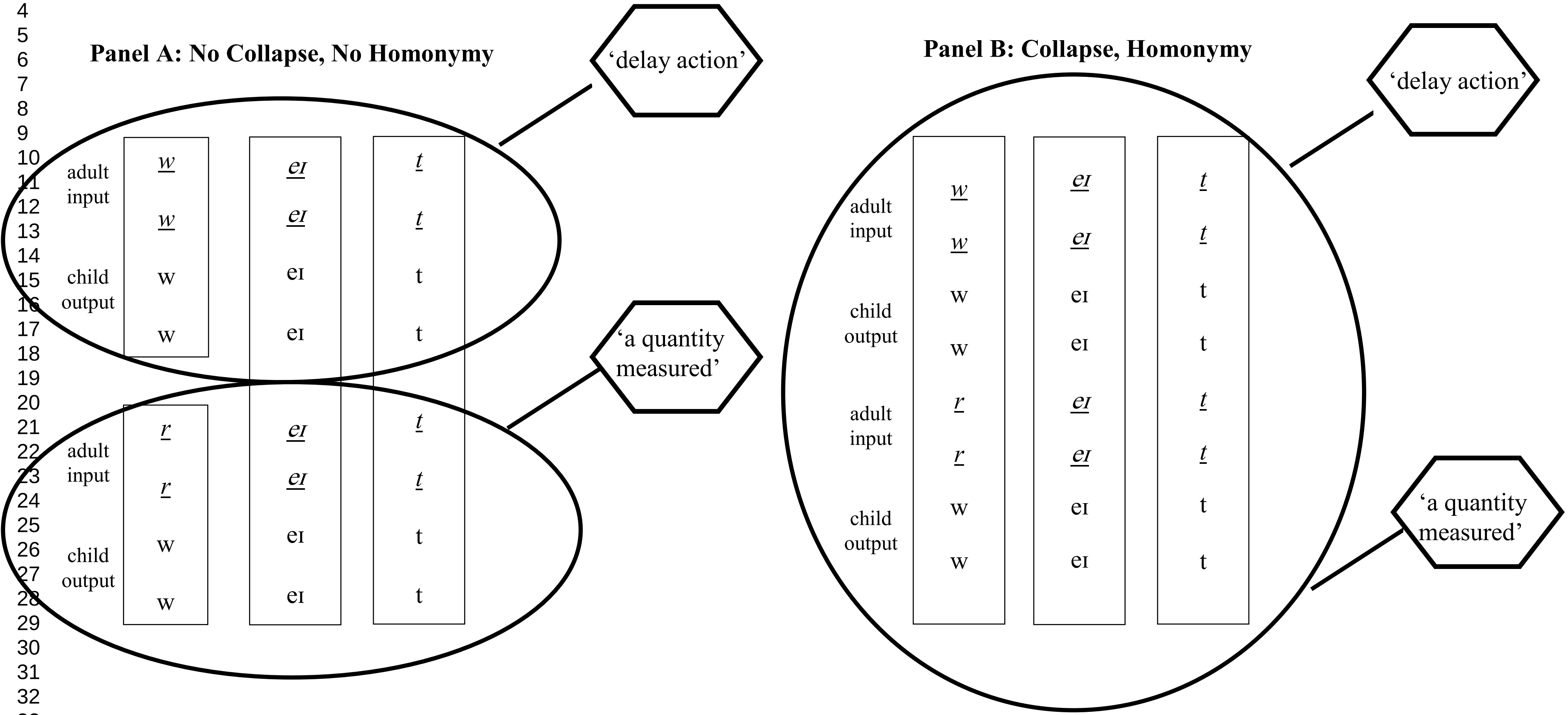

Panel A: No Collapse, No Homonymy
‘delay action’
adult input
child output
w w w w
eɪ eɪ eɪ eɪ
t t t t
‘a quantity measured’
adult input
child output
r r w w
eɪ eɪ eɪ eɪ
t t t t
Panel B: Collapse, Homonymy
‘delay action’
adult input
child output
adult input
child output
w w w w r r w w
eɪ eɪ eɪ eɪ eɪ eɪ eɪ eɪ
t t t t t t t t
‘a quantity measured’

Figure 3

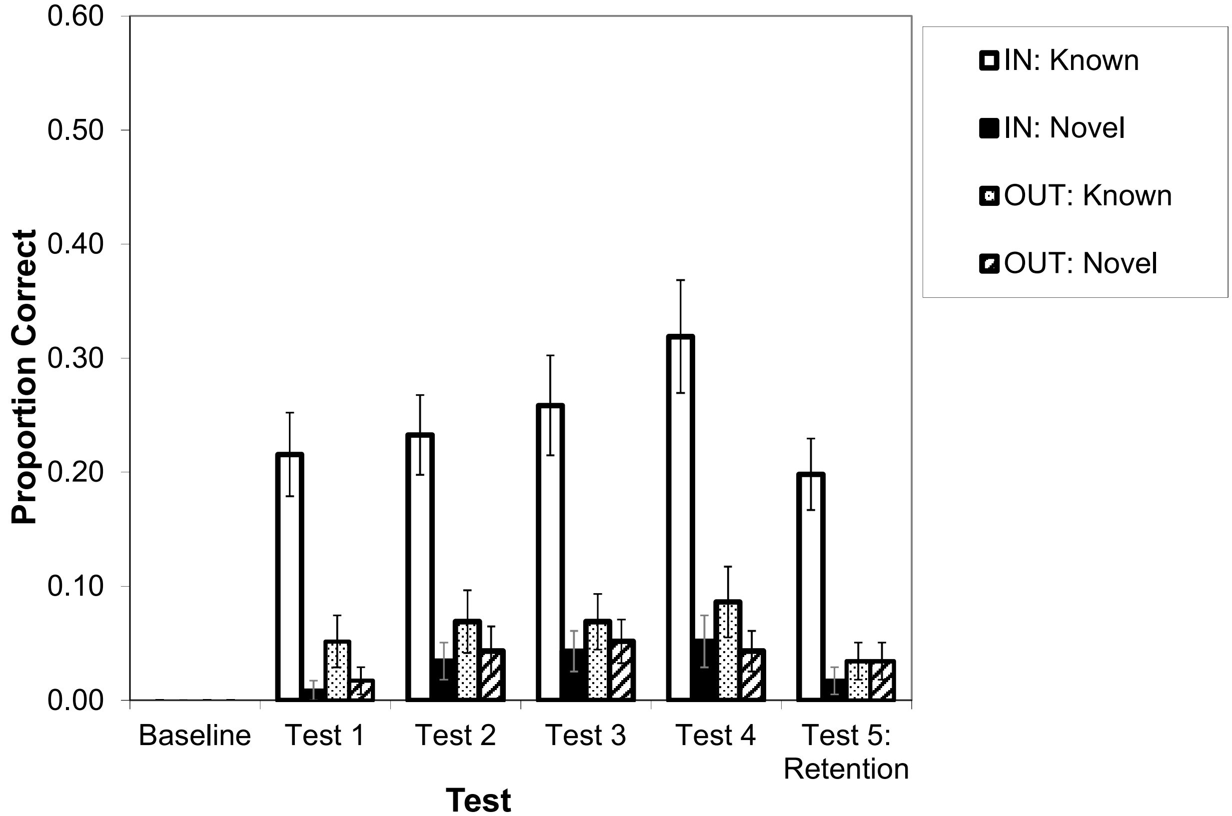
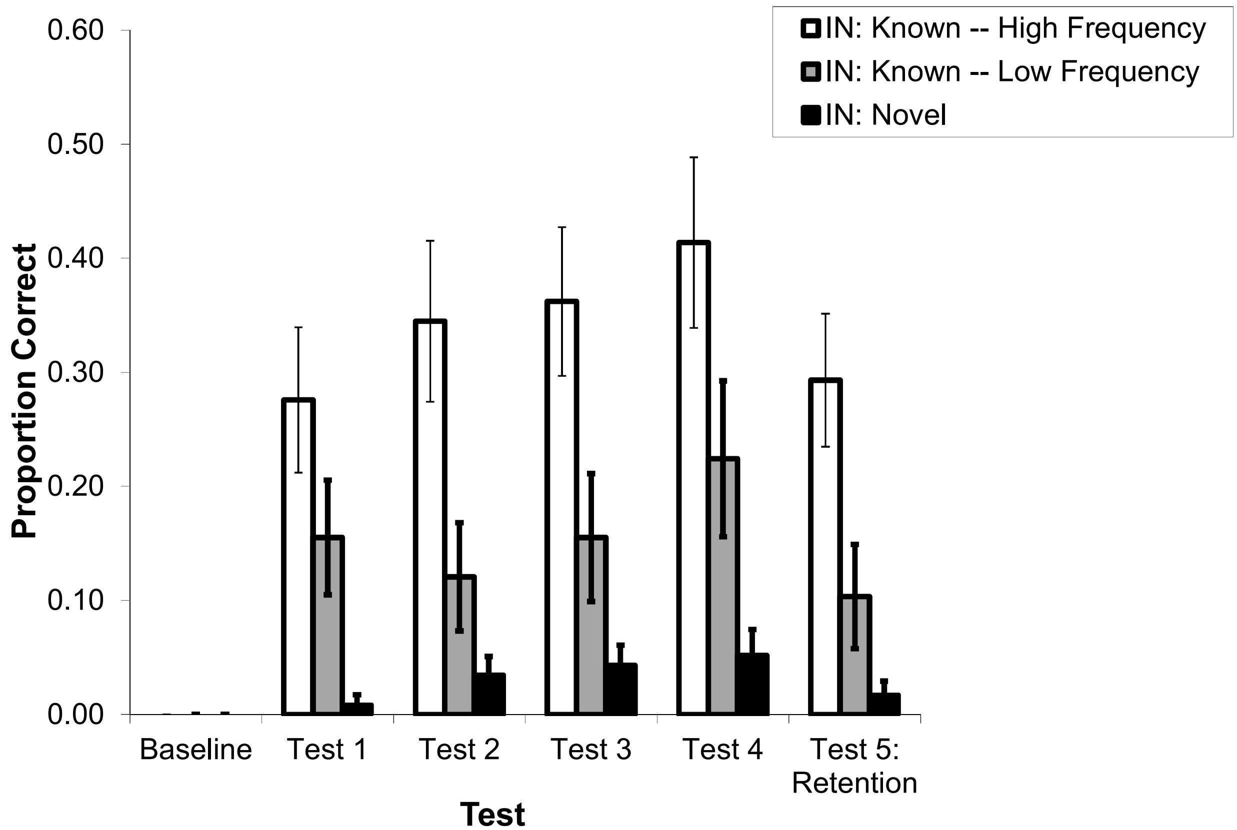

0.60
0.50
0.40
0.30
0.20
0.10
0.00
Proportion Correct
Baseline
Test 1
Test 2
Test 3
Test 4
Test 5: Retention
Test
IN: Known
IN: Novel
OUT: Known
OUT: Novel

Figure 4


IN: Known -- High Frequency
IN: Known -- Low Frequency
IN: Novel
Proportion Correct
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Baseline
Test 1
Test 2
Test 3
Test 4
Test 5: Retention
Test

This document provides supplemental participant information to accompany: Storkel, H. L., Maekawa, J., & Aschenbrenner, A. J. (In Review). The effect of homonymy on learning correctly articulated versus misarticulated words. Speech, Language, and Hearing Research.

The worksheet entitled Participant_Summary provides information concerning each child's production of IN and OUT sounds. Below is a description of each variable included.

Variable	Description
Ss	Arbitrary participant number
OUT Liquid	The target liquid selected for the child and the intended substitute. Written as [substitute] for /target/.
OUT Liquid Constraint	Classification as an inventory or positional constraint based on onset and coda accuracy on the phonological probe, which is displayed in the following two columns.
OUT liquid onset probe accuracy	Accuracy of production of the target in onset position on the phonological probe. Value listed is percent correct.
OUT liquid coda probe accuracy	Accuracy of production of the target in coda position on the phonological probe. Value listed is percent correct.
OUT Liquid "Stimulability"	Classification as stimulable or nonstimulable. This is based on repetition accuracy during the word learning task, which is displayed in the following column. 20% and above was as stimulable. < 20% was categorized as nonstimulable.
OUT Liquid repetition accuracy	Percent correct repetitions during word learning training. Children were given two opportunities to repeat each nonword (n = 4 nonwords for a given sound) during each trainir was repeated 4 times for a maximum of 8 repetition attempts per nonword, which is total of 32 repetition attempts for each sound (i.e., 8 repetitions x 4 nonwords = 32).
OUT Liquid Consistency of Substitute	All children used the intended substitute for the majority of their incorrect productions of the target in onset position. Sounds were categorized as consistent if 100% of their in productions were the intended substitute. Sounds were categorized as majority if < 100% of their incorrect productions were the intended substitute. Data are displayed in the column.
OUT liquid intended onset substitute on probe	Percent of inaccurate productions of the target onset that used the intended substitute on the phonological probe.
OUT Fricative	The target fricative selected for the child and the intended substitute. Written as [substitute] for /target/. Note that 28 of 29 children had 1 liquid and 1 fricative selected as OU Participant CN3-466 was the only child with 2 fricatives selected as OUT sounds. This child is listed twice in the tables to accommodate this difference.
OUT Fricative Constraint	Classification as an inventory or positional constraint based on onset and coda accuracy on the phonological probe, which is displayed in the following two columns.
OUT fricative onset probe accuracy	Accuracy of production of the target in onset position on the phonological probe. Value listed is percent correct.
OUT fricative coda probe accuracy	Accuracy of production of the target in coda position on the phonological probe. Value listed is percent correct.
OUT Fricative "Stimulability"	Classification as stimulable or nonstimulable. This is based on repetition accuracy during the word learning task, which is displayed in the following column. 20% and above was as stimulable. < 20% was categorized as nonstimulable.
OUT Fricative Repetition accuracy	Percent correct repetitions during word learning training. Children were given two opportunities to repeat each nonword (n = 4 nonwords for a given sound) during each trainir was repeated 4 times for a maximum of 8 repetition attempts per nonword, which is total of 32 repetition attempts for each sound (i.e., 8 repetitions x 4 nonwords = 32).
OUT Fricative Consistency of Substitute	All children used the intended substitute for the majority of their incorrect productions of the target in onset position. Sounds were categorized as consistent if 100% of their in productions were the intended substitute. Sounds were categorized as majority if < 100% of their incorrect productions were the intended substitute. Data are displayed in the column.
OUT fricative intended onset substitute on probe	Percent of inaccurate productions of the target onset that used the intended substitute on the phonological probe.
IN Stop	The target stop selected for the child.
IN Stop probe accuracy (all positions)	Accuracy of production of the target in all positions on the phonological probe. Value listed is percent correct.
IN Nasal	The target nasal selected for the child.
IN Nasal probe accuracy (all positions)	Accuracy of production of the target in all positions on the phonological probe. Value listed is percent correct.

The worksheet entitled Liquid_Table extracts the three categorizations (constraint, stimulability, consistency of substitute) for OUT Liquids from the Participant_Summary and provides the count and percent of sounds meeting eac categorization.

The worksheet entitled Fricative_Table extracts the three categorizations (constraint, stimulability, consistency of substitute) for OUT Fricatives from the Participant_Summary and provides the count and percent of sounds meetin categorization.

Note that when comparing the Liquid_Table and Fricative_Table it would appear that children may have had greater knowledge of fricatives than liquids. Using the MLM procedures described in the article, we analyzed the data to det there was a significant difference between the Liquid and Fricative OUT sounds, such that words with one type of sound may have been learned better than words with the other type of sound. No significant difference in learning non Liquids or with Fricatives was observed, $F(1, 2164) = .11$, $p = .74$. Likewise, the same patterns described in the article for OUT sounds as a group were observed for each type of OUT sound (i.e., liquids and fricatives).

Production Probe Accuracy for OUT and IN sounds by position (onset, coda) and across position (ALL)

Ss	OUT Liquid	OUT Liquid Constraint	OUT liquid onset probe accuracy	OUT liquid coda probe accuracy	OUT Liquid "Stimulability"	OUT Liquid repetition accuracy	OUT Liquid Consistency of Substitute	OUT liquid intended onset substitute on probe	OUT Fricative	OUT Fricative Constraint	OUT fricative onset probe accuracy	OUT fricative coda probe accuracy	OUT Fricative "Stimulability"	OUT Fricative Repetition accuracy	OUT Fricative Consistency of Substitute	OUT fricative intended onset substitute on probe	IN Stop	IN Stop probe accuracy (all positions)	IN Nasal	IN Nasal probe accuracy (all positions)
CN3-316	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[s] for /esh/	inventory	20	0	nonstimulable	6	consistent	100	b	100	m	100
CN3-317	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	consistent	100	p	100	n	100
CN3-324	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[s] for /esh/	inventory	0	0	nonstimulable	0	consistent	100	b	100	m	90
CN3-369	[w] for /r/	inventory	0	20	nonstimulable	0	consistent	100	[s] for /esh/	inventory	0	0	nonstimulable	0	consistent	100	b	100	m	100
CN3-394	[w] for /r/	inventory	0	0	nonstimulable	7	consistent	100	[s] for /esh/	inventory	0	0	nonstimulable	0	consistent	100	b	100	m	100
CN3-417	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[b] for /v/	inventory	0	0	nonstimulable	0	consistent	100	k	100	m	100
CN4-336	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	consistent	100	p	100	n	100
CN4-345	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[s] for /esh/	inventory	20	0	nonstimulable	0	consistent	100	b	100	m	100
CN4-353	[w] for /l/	inventory	0	0	nonstimulable	0	consistent	100	[s] for /esh/	inventory	20	0	nonstimulable	0	consistent	100	b	90	m	90
CN4-414	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	consistent	100	p	100	n	100
CN4-444	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	20	0	nonstimulable	0	consistent	100	p	100	n	100
CN3-266	[w] for /r/	inventory	0	0	stimulable	31	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	consistent	100	p	100	n	100
CN4-470	[w] for /l/	positional	0	100	stimulable	56	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	consistent	100	t	100	n	100
CN3-310	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	majority	60	p	100	n	100
CN3-311	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	majority	60	p	100	n	100
CN4-323	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[s] for /theta/	inventory	0	0	nonstimulable	19	majority	80	k	100	n	100
CN4-339	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[s] for /theta/	inventory	20	0	nonstimulable	0	majority	80	k	100	n	100
CN4-349	[w] for /r/	positional	0	100	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	majority	80	p	100	n	100
CN4-352	[w] for /r/	positional	0	100	nonstimulable	0	consistent	100	[f] for /theta/	inventory	0	0	nonstimulable	0	majority	80	p	100	n	100
CN3-347	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[b] for /v/	inventory	0	0	stimulable	22	consistent	100	k	100	m	100
CN3-393	[w] for /r/	inventory	20	0	nonstimulable	0	consistent	100	[s] for /esh/	inventory	0	0	stimulable	23	consistent	100	b	100	m	100
CN3-411	[w] for /l/	inventory	0	0	nonstimulable	0	consistent	100	[f] for /theta/	inventory	20	0	stimulable	92	consistent	100	t	100	n	100
CN4-425	[w] for /r/	inventory	0	0	nonstimulable	7	consistent	100	[f] for /theta/	inventory	20	0	stimulable	88	consistent	100	p	100	n	100
CN3-319	[w] for /r/	positional	0	100	nonstimulable	0	consistent	100	[b] for /v/	inventory	20	0	stimulable	32	consistent	100	k	100	m	100
CN3-358	[w] for /r/	inventory	0	0	stimulable	27	consistent	100	[f] for /theta/	inventory	0	0	stimulable	33	majority	80	p	100	n	100
CN3-424	[w] for /r/	inventory	0	0	nonstimulable	4	consistent	100	[b] for /v/	positional	20	100	stimulable	100	consistent	100	k	100	m	100
CN3-446	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[b] for /v/	positional	20	80	stimulable	100	consistent	100	k	100	m	100
CN3-448	[w] for /r/	inventory	0	0	nonstimulable	0	consistent	100	[b] for /v/	positional	0	60	stimulable	43	consistent	100	k	100	m	100
CN3-466	2 fricatives selected as OUT sounds for this participant								[f] for /theta/	positional	20	40	stimulable	100	consistent	100	b	100	p	100
CN3-466									[s] for /esh/	inventory	0	0	stimulable	55	consistent	100	see above			

Ss	OUT Liquid	OUT Liquid Constraint	OUT Liquid "Stimulability"	OUT Liquid Consistency of Substitute	Summary (number)	Summary (percent)
CN3-316	[w] for /r/	inventory	nonstimulable	consistent		
CN3-317	[w] for /r/	inventory	nonstimulable	consistent		
CN3-324	[w] for /r/	inventory	nonstimulable	consistent		
CN3-369	[w] for /r/	inventory	nonstimulable	consistent		
CN3-394	[w] for /r/	inventory	nonstimulable	consistent		
CN3-417	[w] for /r/	inventory	nonstimulable	consistent		
CN4-336	[w] for /r/	inventory	nonstimulable	consistent		
CN4-345	[w] for /r/	inventory	nonstimulable	consistent		
CN4-353	[w] for /l/	inventory	nonstimulable	consistent		
CN4-414	[w] for /r/	inventory	nonstimulable	consistent		
CN4-444	[w] for /r/	inventory	nonstimulable	consistent		
CN3-310	[w] for /r/	inventory	nonstimulable	consistent		
CN3-311	[w] for /r/	inventory	nonstimulable	consistent		
CN4-323	[w] for /r/	inventory	nonstimulable	consistent		
CN4-339	[w] for /r/	inventory	nonstimulable	consistent		
CN3-347	[w] for /r/	inventory	nonstimulable	consistent		
CN3-393	[w] for /r/	inventory	nonstimulable	consistent		
CN3-411	[w] for /l/	inventory	nonstimulable	consistent		
CN4-425	[w] for /r/	inventory	nonstimulable	consistent		
CN3-424	[w] for /r/	inventory	nonstimulable	consistent		
CN3-446	[w] for /r/	inventory	nonstimulable	consistent		
CN3-448	[w] for /r/	inventory	nonstimulable	consistent	n = 22 inventory, nonstimulable, consistent substitute	79% inventory, nonstimulable, consistent substitute
CN3-266	[w] for /r/	inventory	stimulable	consistent		
CN3-358	[w] for /r/	inventory	stimulable	consistent	n = 2 inventory, stimulable, consistent substitute	7% inventory, stimulable, consistent substitute
CN4-349	[w] for /r/	positional	nonstimulable	consistent		
CN4-352	[w] for /r/	positional	nonstimulable	consistent		
CN3-319	[w] for /r/	positional	nonstimulable	consistent	n = 3 positional, nonstimulable, consistent substitute	11% positional, nonstimulable, consistent substitute
CN4-470	[w] for /l/	positional	stimulable	consistent	n = 1 positional, stimulable, consistent substitute	4% positional, stimulable, consistent substitute

Ss	OUT Fricative	OUT Fricative Constraint	OUT Fricative "Stimulability"	OUT Fricative Consistency of Substitute	Summary (number)	Summary (percent)
CN3-316	[s] for /esh/	inventory	nonstimulable	consistent		
CN3-317	[f] for /theta/	inventory	nonstimulable	consistent		
CN3-324	[s] for /esh/	inventory	nonstimulable	consistent		
CN3-369	[s] for /esh/	inventory	nonstimulable	consistent		
CN3-394	[s] for /esh/	inventory	nonstimulable	consistent		
CN3-417	[b] for /v/	inventory	nonstimulable	consistent		
CN4-336	[f] for /theta/	inventory	nonstimulable	consistent		
CN4-345	[s] for /esh/	inventory	nonstimulable	consistent		
CN4-353	[s] for /esh/	inventory	nonstimulable	consistent		
CN4-414	[f] for /theta/	inventory	nonstimulable	consistent		
CN4-444	[f] for /theta/	inventory	nonstimulable	consistent		
CN3-266	[f] for /theta/	inventory	nonstimulable	consistent		
CN4-470	[f] for /theta/	inventory	nonstimulable	consistent	n = 13 inventory, nonstimulable, consistent substitute	43% inventory, nonstimulable, consistent substitute
CN4-323	[s] for /theta/	inventory	nonstimulable	majority		
CN4-339	[s] for /theta/	inventory	nonstimulable	majority		
CN4-349	[f] for /theta/	inventory	nonstimulable	majority		
CN4-352	[f] for /theta/	inventory	nonstimulable	majority		
CN3-310	[f] for /theta/	inventory	nonstimulable	majority		
CN3-311	[f] for /theta/	inventory	nonstimulable	majority	n = 6 inventory, nonstimulable, majority substitute	20% inventory, nonstimulable, majority substitute
CN3-347	[b] for /v/	inventory	stimulable	consistent		
CN3-393	[s] for /esh/	inventory	stimulable	consistent		
CN3-411	[f] for /theta/	inventory	stimulable	consistent		
CN4-425	[f] for /theta/	inventory	stimulable	consistent		
CN3-319	[b] for /v/	inventory	stimulable	consistent		
CN3-466	[s] for /esh/	inventory	stimulable	consistent	n = 6 inventory, stimulable, consistent substitute	20% inventory, stimulable, consistent substitute
CN3-358	[f] for /theta/	inventory	stimulable	majority	n = 1 inventory, stimulable, majority substitute	3% inventory, stimulable, majority substitute
CN3-424	[b] for /v/	positional	stimulable	consistent		
CN3-446	[b] for /v/	positional	stimulable	consistent		
CN3-448	[b] for /v/	positional	stimulable	consistent		
CN3-466	[f] for /theta/	positional	stimulable	consistent	n = 4 positional, stimulable, consistent substitute	13% positional, stimulable, consistent substitute

2 fricatives selected for CN3-466 rather than 1 fricative + 1 liquid. Participant is listed twice in the table for this reason.