The Emerging Lexicon of Children with Phonological Delays: Phonotactic Constraints and Probability in Acquisition

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Abstract

The effects of phonotactic constraints (i.e., the status of a sound as correctly or incorrectly articulated) and phonotactic probability (i.e., the likelihood of a sound sequence) on lexical acquisition have been investigated independently. This study investigated the interactive influence of phonotactic constraints and phonotactic probability on lexical acquisition in three groups of children: children with functional phonological delays (PD), phonology-matched younger typically developing children (PM), and age-/vocabulary-matched typically developing peers (AVM). Sixty-eight children participated in a multitrial word-learning task involving nonwords varying in phonotactic constraints (IN vs. OUT) and phonotactic probability (common vs. rare). Correct and error responses were analyzed. Results indicated that OUT sound sequences were learned more rapidly than IN sound sequences. This suggests that OUT sounds may be salient because they represent only a small subset of the child's sound system. The effect of phonotactic probability varied across groups: children with PD showed a common sound sequence disadvantage, younger PM children showed a common sound sequence advantage, and AVM children showed no effect. Moreover, error analyses indicated that children with PD had particular difficulty creating lexical representations and associations between lexical and semantic representations when learning common sound sequences. Children with PD may rely more heavily on lexical representations to learn new words or may have difficulty learning common sound sequences because of the high degree of similarity between these sequences and other known words. Finally, the effect of phonotactic probability was consistent across IN and OUT sound sequences, suggesting that the lexical representation of both correctly articulated and misarticulated words is based on the adult-target pronunciation.

Key Words: phonological disorders, vocabulary expansion, preschool children, phonotactic constraints, phonotactic probability

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Current theories propose that a lexical entry in memory consists of three types of representations: phonological, lexical and semantic (e.g., Dell, 1988; Luce, Goldinger, Auer, & Vitevitch, 2000; Stemberger, 1992; Vitevitch & Luce, 1999). The *phonological representation* refers to the individual sounds that comprise a given word, with each sound being viewed as a separate unit (e.g., Luce et al., 2000; Vitevitch & Luce, 1999). In contrast, the *lexical representation* refers to the word's sound sequence as an integrated whole (e.g., Luce et al., 2000; Vitevitch & Luce, 1999). Finally, the *semantic representation* refers to the word's meaning or referent (e.g., Stemberger, 1992). Children acquiring a language are faced with learning all three representations in parallel. Given this simultaneous acquisition, it is possible that phonological acquisition may influence lexical acquisition. This issue of the interaction between phonological and lexical development is particularly important to consider for children with functional phonological delays (PD). These children experience delays in the acquisition of productive phonology in the absence of any concomitant social, cognitive, sensory, or motor deficits. If phonological development affects lexical acquisition, then children with PD may be at risk for deficits in lexical acquisition. Emerging evidence indicates that two aspects of phonology, phonotactic constraints and phonotactic probability, shape lexical acquisition, but the implications for children with PD currently are unclear.

Phonotactic constraints

Phonotactic constraints, as applied to acquisition, are rules that describe for a given child the set of sounds that occur in production (i.e., inventory constraints), context conditioned limitations in sound occurrence (i.e., positional constraints), and restrictions on the co-occurrence of sounds (i.e., sequence constraints, see Dinnsen, 1984; Elbert & Gierut, 1986 for fuller discussion). In this way, phonotactic constraints describe a child's unique set of rules that define which sounds are produced, namely *IN* sounds, and which sounds are not produced, namely *OUT* sounds. Previous work suggests that phonotactic constraints may act as a filter for lexical acquisition (Vihman, 1993). In support of this hypothesis, typically developing children appear to learn words that are consistent with the phonotactic constraints observed in their babbling or first words (e.g., Ferguson & Farwell, 1975; Stoel-Gammon & Cooper, 1984; Velleman, 2002; Vihman, Ferguson, & Elbert, 1986; Vihman, Macken, Miller, Simmons, & Miller, 1985). That is, early vocabularies tend to include more words composed of IN than OUT sounds. Experimental studies provide further evidence that phonotactic constraints influence lexical acquisition (Leonard, Schwartz, Morris, & Chapman, 1981; Schwartz & Leonard, 1982; Schwartz, Leonard, Loeb, & Swanson, 1987). In these studies, typically developing children with productive vocabularies of 50 words or less were exposed to novel words composed of IN sounds and those composed of OUT sounds. Here, IN sounds were defined as sounds that were observed in production (Schwartz & Leonard, 1982) or sounds that were produced with at least 50-67% accuracy (Leonard et al., 1981; Schwartz et al., 1987). In contrast, OUT sounds were defined as sounds that were not produced and were not characteristic of the words attempted by the child (Leonard et al., 1981; Schwartz & Leonard, 1982; Schwartz et al., 1987). Across these studies, children more readily learned to produce words composed of IN sounds than those composed of OUT sounds.

Taken together, phonotactic constraints appear to influence lexical acquisition by typically developing children with this influence emerging early in development; however, what remains less clear is the role that phonological development plays in promoting or curtailing this influence. Previous studies have focused primarily on children at the earliest stage of lexical development and those with age-appropriate phonological development. It is possible that phonotactic constraints may continue to act as a filter for lexical acquisition even after the 50-word stage in children with PD. In this way, phonotactic constraints could limit the words that children with PD learn. The first goal of this study was to test this hypothesis by comparing learning of novel words composed of IN sounds to learning of novel words composed of OUT sounds by children with PD.

Phonotactic probability

A second variable that has been shown to affect lexical acquisition in typically developing children is phonotactic probability. *Phonotactic probability* refers to the likelihood of occurrence of a sound sequence in a language and differentiates sound sequences that are common from those that are rare. A sound sequence is considered *common* if the individual sounds and adjacent sounds occur in the same word position in many other words of the language (e.g., “coat”). In contrast, a sound sequence is considered *rare* if the individual sounds and adjacent sounds occur in few other words (e.g., “watch”). Phonotactic probability appears to influence lexical acquisition by typically developing preschool and school-age children (Storkel, 2001, 2003; Storkel & Rogers, 2000). In Storkel (2001, 2003), children were exposed to phonotactically permissible nonwords composed of either common (e.g., /pin/) or rare sequences (e.g., /mɔɪd/). These nonwords were paired with semantically matched novel referents. (e.g., two different candy machines). Results showed that children learned common sound sequences more rapidly than rare (Storkel, 2001, 2003). It was hypothesized that children used their phonological representations to support lexical acquisition and that common sound sequences facilitated phonological processing, increasing the speed of learning of these sound sequences.

Storkel (2001) also analyzed error responses in picture naming to provide insights into the mechanism underlying the common sound sequence advantage. Two types of errors were possible: semantic or unrelated. Semantic errors occurred when the child responded with the nonword name of the semantically related novel object. For example, when shown the picture of the candy machine labeled /mɔɪd/, a child might produce the name of the other candy machine, /pin/. In complement, unrelated errors occurred when the child responded with the nonword name of a semantically unrelated novel object. For example, when shown the picture of the toy labeled /naʊb/, a child might respond with the name of one of the candy machines, e.g., /pin/. Storkel (2001) proposed that these two types of errors provided a window into the formation of mental representations. Semantic errors were thought to arise from a holistic semantic representation, consisting primarily of category specification (e.g., candy machine) but insufficient detail to differentiate the two related referents. Semantic errors also were thought to indicate which lexical representation was more strongly associated with the holistic semantic representation. To illustrate, when the child saw a picture of one of the candy machines, the holistic semantic representation would be activated. This, in turn, would activate one lexical representation, either that of the common or the rare sound sequence, more strongly than the other. Results indicated that when shown the referent of one of the rare sound sequences, children tended to respond with the common sound sequence that labeled the semantically related object. Thus, it appeared that the lexical representation of common sound sequences, rather than rare sound sequences, was more strongly associated with a semantic representation. This suggests that phonotactic probability influenced the strength of an association between lexical and semantic representations.

Turning to the unrelated errors, Storkel (2001) hypothesized that unrelated errors were attributable to deficits in the association between lexical and semantic representations. Moreover, it was assumed that the identity of the unrelated substitute was revealing of the status of the lexical representation of that substitute. That is, production of a nonword in any context was thought to indicate that the lexical representation was intact or at least holistic; however, if the child produced that sound sequence as the name of a semantically unrelated object, then that may indicate the lack of association between the intact lexical representation and an appropriate semantic representation. Presumably, association with a holistic or intact semantic representation would block the use of the nonword in response to a semantically unrelated target. To illustrate, if the child saw a picture of one of the candy machines, then the target semantic representation might be activated; however, this may fail to trigger the activation of an appropriate lexical representation. In this case, the child may respond with a nonword that was semantically unrelated to the picture. The child's production of this nonword, indicates the presence of a lexical representation that is complete enough to support production. Results showed that unrelated error rates were similar across common and rare sound sequences. More importantly, analysis of the phonotactic probability of the substitutes showed that children produced rare sound sequences more often than common as substitutes for unrelated target objects. This pattern suggests an intact lexical representation of rare sound sequences but the lack of an association with an appropriate semantic representation. Taken together, common sound sequences were thought to facilitate phonological processing which in turn improved the learning of an association between lexical and semantic representations, speeding lexical acquisition.

While the effect of phonotactic probability on word learning appears robust, the influence of phonological development on this effect is unclear. Past research shows that children with PD do learn phonotactic probability, and this does influence production, where common sound sequences are produced more accurately than rare (Beckman & Edwards, 2000). Thus, it is possible that children with PD, like children with age-appropriate phonological development, may learn common sound sequences more rapidly than rare (i.e., common sound sequence advantage) because common sound sequences may facilitate phonological processing by children with PD, speeding the learning of an association between newly formed lexical and semantic representations. Alternatively, children with PD may learn common sound sequences more slowly than rare (i.e., common sound sequence disadvantage) because of the inherent similarity between common sound sequences and other words of the language (Vitevitch, Luce, Pisoni, & Auer, 1999). Specifically, common sound sequences tend to be phonologically similar to many other words in the language, whereas rare sound sequences tend to be phonologically similar to only a few other words in the language. For this reason, children with PD may have difficulty establishing a lexical representation for a novel common sound sequence that differentiates this newly formed lexical representation from that of known words. In this way, common sound sequences may inhibit lexical processing by children with PD, slowing the learning of a unique lexical representation. The second goal of this study was to determine whether children with PD showed a common sound sequence advantage in lexical acquisition due to ease in creating an association between lexical and semantic representations, or a common sound sequence disadvantage due to difficulty creating unique lexical representations.

Interaction of constraints and probabilities

While past evidence suggests that phonotactic constraints and phonotactic probability influence lexical acquisition, it is unclear whether these two variables interact in lexical acquisition. The crux of this question relates to the nature of the lexical representation of words composed of OUT sounds. Some argue that the lexical representation of words composed of OUT sounds is target appropriate (e.g., Dinnsen, 2002; Dinnsen, O'Connor, & Gierut, 2001; Donegan & Stampe, 1979; Kager, 1999; Menn, 1978; Smith, 1973). For example, given the substitute of [fɪn] for /θɪn/, the child’s lexical representation is assumed to be based on the adult target /θɪn/. Alternatively, others suggest that the lexical representation of at least some words composed of OUT sounds may not be target appropriate (Dinnsen, 1984; Dinnsen & Maxwell, 1981; e.g., Macken, 1980; Maxwell, 1984; see alsoVihman, 1982 for specific examples regarding /θ/-/f/ confusions). Under this view, the lexical representation is assumed to be based on the child’s production, e.g., [fɪn].

These arguments concerning the nature of lexical representations have been levied for both typically developing children and children with PD. A variety of evidence has been used to infer the status of lexical representations including morphophonemic alternations (e.g., Dinnsen, Elbert, & Weismer, 1981; Dinnsen & Maxwell, 1981), interacting error patterns (e.g., Williams & Dinnsen, 1987), imperceptible but reliable acoustic contrasts in production (e.g., Forrest & Rockman, 1988; Forrest, Weismer, Hodge, Dinnsen, & Elbert, 1990; Gierut & Dinnsen, 1986; Maxwell & Weismer, 1982; Tyler, Edwards, & Saxman, 1990; Weismer, Dinnsen, & Elbert, 1981), perceptual discrimination of contrasts (e.g., Locke, 1980; McGregor, 1992; Tyler et al., 1990), and learning patterns (e.g., Dinnsen & Elbert, 1984; Tyler et al., 1990). In all cases, the status of underlying lexical representations has been inferred by examining the production, perception, or learning of phonological contrasts. We propose to bring a different type of evidence to bear on this debate, namely evidence from lexical acquisition. Specifically, assumptions concerning the lexical representation of words composed of OUT sounds have consequences for predicting the effect of phonotactic probability on lexical acquisition. To illustrate, consider again the child who produces [fɪn] for /θɪn/. If it is assumed that the lexical representation of words composed of OUT sounds is based on the adult target, then the phonotactic probability would be based on /θɪn/, which is a rare sound sequence. In contrast, if it is assumed that the lexical representation of words composed of OUT sounds is based on the child's production, then the phonotactic probability would be based on [fɪn], which is a common sound sequence. The consequence of this difference in the nature of the lexical representation is that different rates of word learning would be predicted. Under the first hypothesis, the sound sequence is considered rare and would be learned relatively slowly. Under the second hypothesis, the sound sequence is considered common and would be learned relatively quickly.

One way to address the issue of the lexical representation of words composed of OUT sounds is to examine the effect of phonotactic probability on the learning of IN sound sequences, where the lexical representation is assumed to be based on the adult target pronunciation, and compare that to the effect of phonotactic probability on the learning of OUT sound sequences, where the basis of the lexical representation is unclear. If the effect of phonotactic probability is the same for both IN and OUT sound sequences, then this would support the hypothesis that lexical representations of both IN and OUT sound sequences are based on the adult target pronunciation. On the other hand, if the effect of phonotactic probability on the learning of IN sound sequences differs from that of OUT sound sequences, then this would suggest that the lexical representations of IN sound sequences differs from that of OUT sound sequences. A finding of this type would suggest that the lexical representation of OUT sound sequences may be based on the child's pronunciation. The third goal of this study was to compare the effect of phonotactic probability on the learning of IN sounds to that of OUT sounds to provide insights about the status of lexical representations of misarticulated words.

The goals of this study were to (1) determine whether phonotactic constraints influence word learning by children with PD; (2) examine whether phonotactic probability influences word learning by children with PD in the same way as typically developing children; (3) investigate the status of lexical representations of words composed of OUT sounds. Specific questions were:

1. Do children with PD learn novel words composed of IN sounds more rapidly or more slowly than novel words composed of OUT sounds?
2. Do children with PD learn common sound sequences more rapidly or more slowly than rare sound sequences and do they have difficulty with specific aspects of the lexical acquisition process as revealed through error analyses?
3. Is the effect of phonotactic probability (i.e., common sound sequence advantage vs. disadvantage) on lexical acquisition consistent or variable across IN versus OUT sounds?

These questions were addressed by examining lexical acquisition by three groups of children: (1) children with PD; (2) younger phonology-matched typically developing children (PM); (3) age-/vocabulary-matched typically developing children (AVM). These two control groups were selected to differentiate the effects of phonological development from those of cognitive/experiential (as indexed by age) and vocabulary development. The nonwords to be learned orthogonally varied in phonotactic constraints (IN vs. OUT) and phonotactic probability (common vs. rare). It was necessary to select children who produced specific sounds accurately (i.e., IN sounds) versus in error (i.e., OUT sounds) so that the same stimuli could be used across children. Based on normative data, /m g/ were chosen as IN sounds and /r θ/ were chosen as OUT sounds (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). The effect of the independent variables on correct responses was analyzed to determine which factors significantly influenced acquisition. In addition, errors were analyzed to determine which aspects of the acquisition process were vulnerable to failure.

Method

Participants

Three groups of children were recruited via public announcement. All children were monolingual native English speakers and passed a hearing screening prior to participation (ASHA, 1997). None of the children had a history of cognitive, social, motor, visual or major medical disorder by parent report. Table 1 displays the mean standardized test performance for each group. Vocabulary development was age-appropriate (Dunn & Dunn, 1997; Williams, 1997).

Groups were defined based on performance on standardized phonology tests and on elicited probe measures. The *full real word probe* sampled all English consonants in each relevant word position in a minimum of five different words (Gierut, 1985). The *brief real word probe* consisted of a subset of items from the full real word probe, namely those targeting /m ɡ r θ/. In both cases, probe items were elicited through spontaneous picture naming. In addition, a *nonword probe* was used to elicit production of the experimental stimuli (described below). Each nonword was elicited in direct imitation three times. Both speech samples were audio recorded and phonetically transcribed. Real words were then analyzed by computing accuracy and substitution patterns for each target phoneme in English (i.e., relational analyses) and constructing phonetic and phonemic inventories (i.e., independent analyses, Dinnsen, Chin, Elbert, & Powell, 1990; Gierut, Simmerman, & Neumann, 1994). Nonwords were analyzed in terms of accuracy and substitution patterns. Results of the accuracy analyses for both real words and nonwords are shown in Table 1.

The first group consisted of 20 children (*M* age = 60 months; *SD* = 9) with functional phonological delays (PD group). A functional phonological delay was defined using a liberal criterion: (1) score one standard deviation below the mean or lower on the *Goldman-Fristoe Test of Articulation -2* (GFTA, Goldman & Fristoe, 2000); (2) scores within one standard deviation of the mean or higher on language and cognitive measures (Hresko, Reid, & Hammill, 1999; Roid & Miller, 1997). In addition, based on the analysis of the full real word and nonword production probes, /m g/ were IN sounds, meeting the following criteria (1) greater than 50% production accuracy in word-initial position of real words (c.f., Gierut, 1996); (2) greater than 50% accuracy in producing the nonword stimuli; (3) lack of inventory or word-initial positional constraints. In contrast, /r θ/ were OUT sounds, meeting the following criteria: (1) less than 50% production accuracy in word-initial position of real words (cf., Gierut, 1996); (2) less than 50% accuracy in producing the nonword stimuli; (3) inventory or word-initial positional constraint. The majority of the children evidenced inventory constraints, rather than positional constraints, for both /r/ and /θ/ (75% and 95% respectively).

The second group consisted of 24 younger children (*M* age = 46 months; *SD* = 8) who were matched on production accuracy for /m ɡ r θ/ to the PD group; however, children in this group demonstrated age-appropriate phonological development (Goldman & Fristoe, 2000). Children in this phonology-matched group (PM group) met the same production criteria as the children in the PD group. Real word and nonword accuracy data from the PD and PM groups were submitted to a *t* test analysis. Generally, accuracy in real words and nonwords did not differ between the two groups, all ts (42) < 1.50, all ps > 0.15. The only exception was /θ/ accuracy in word-initial position of real words, where the PD group was more accurate than the PM group, t (42) = -2.08, p = 0.05.

The third group consisted of 24 children (*M* age = 57 months; *SD* = 10) who were matched on chronological age and raw vocabulary scores (AVM group) to the children in the PD group (Dunn & Dunn, 1997; Williams, 1997). Age and vocabulary scores were submitted to a *t* test analysis, which showed no significant difference between the groups, all ts (42) < 1.30, all ps > 0.20. The AVM group demonstrated age-appropriate phonological development. In contrast to the two previous groups, the AVM group correctly articulated all target sounds because it was not possible identify children at this age with age-appropriate phonological development who misarticulated both /r/ and /θ/. Children who misarticulated either /r/ or /θ/ were excluded to avoid variability in categorization of /r/ and /θ/ across children. This stipulation led to relatively high performance on the GFTA for this group.

Stimuli

Nonwords. The two independent variables manipulated in creating the nonwords were phonotactic constraints and phonotactic probability. Phonotactic constraints were dictated by the characteristics of the participants, with /m g/ being IN sounds for all three groups and /r θ/ being OUT sounds for the PD and PM groups. Consonant-vowel-consonant (CVC) nonwords were generated that contained these sounds in word-initial position. Final consonants were selected from the set of sounds that were correctly articulated by all three groups (i.e., /m n p b t d f/).

The phonotactic probability was then computed for the generated nonwords based on the adult target pronunciation. Phonotactic probability was determined using a 20,000 word computer readable dictionary (Nusbaum, Pisoni, & Davis, 1984). Two measures were computed: positional segment frequency and biphone frequency. *Positional segment frequency* is the likelihood of occurrence of a given sound in a given word position. This is computed by summing the log frequency of all the words in the dictionary containing a particular sound in a particular word position and dividing by the sum of the log frequency of all of the words in the dictionary containing any sound in the same word position. *Biphone frequency* is the likelihood of occurrence of two adjacent sounds. It is computed by summing the log frequency of all of the words in the dictionary containing a particular biphone in a particular word position and dividing by the sum of the log frequency of all of the words in the dictionary containing any biphone in the same word position (see also Storkel, 2001). Common sound sequences were defined as those having a positional segment frequency of 0.11 or greater and a biphone frequency of 0.0028 or greater. These cut-offs approximate a median split of all possible legal CVCs. From the pool of CVCs composed of IN sounds, four common and four rare sound sequences were selected. From the pool of CVCs containing OUT sounds in word-initial position, four common and four rare sound sequences were selected. The left-hand columns of Table 2 display the mean positional segment and biphone frequencies for each condition. Table 3 shows the selected nonwords.

The above description of the calculation of phonotactic probability for the OUT stimuli assumes that the PD and PM groups would create a lexical representation of the OUT nonwords based on the adult target. Alternatively, it is possible that the PD and/or PM groups might create a lexical representation of the OUT nonwords based on their own production. To examine the effect of this alternative hypothesis, the phonotactic probability was computed based on the child's pronunciation of the OUT stimuli. For the common OUT nonwords, phonotactic probability was computed based on a [w] substitute for /r/. Mean positional segment frequency and biphone frequency based on the child's surface production are shown in the right-hand columns of Table 2. As expected, this surface-production phonotactic probability reversed the phonotactic probability from common to rare. For the rare OUT nonwords, phonotactic probability was computed based on a [t], [f], or [s] substitute for /θ/. As expected, computations based on the child's pronunciation reversed the categorization of the nonwords from rare to common. In the following sections, when the phonotactic probability of the OUT stimuli is referred to, the reference point will be that of the target adult pronunciation.

This reversal of phonotactic probability based on adult versus child pronunciation may provide crucial insights into the lexical representation of OUT sound sequences. Specifically, if the effect of phonotactic probability (i.e., common sound sequence advantage vs. disadvantage) based on the target adult pronunciation is similar across IN and OUT sound sequences, then this would provide support that the lexical representation of both IN and OUT sound sequences are based on the adult target pronunciation. In contrast, if the effect of phonotactic probability (i.e., common sound sequence advantage vs. disadvantage) based on the adult target pronunciation is dissimilar across IN and OUT sound sequences, then this reversal of phonotactic probability may reconcile the observed difference. For example, if results based on the adult target pronunciation show a common sound sequence advantage for IN sounds and a common sound sequence disadvantage for OUT sounds, then appealing to the phonotactic probability based on the child surface pronunciation would reverse the phonotactic probability of the rare OUT sound sequences to common. In this way, one possible conclusion is that children showed a common sound sequence advantage for both IN and OUT sounds, but for IN sounds the phonotactic probability was based on the adult target pronunciation and for OUT sounds the phonotactic probability was based on the child's surface pronunciation. This would support the hypothesis that the lexical representation of IN sound sequences is based on the adult target, whereas the lexical representation of OUT sound sequences is based on the child's surface pronunciation. Note that the calculation of phonotactic probability based on the child's surface pronunciation is viewed as being relevant *only* if the results show a different effect of phonotactic probability (i.e., common sound sequence advantage vs. disadvantage) across IN and OUT sound sequences.

Referents. Object referents were either created or adapted from children's stories. Table 3 describes the 16 object referents that were paired with the nonwords. In an attempt to equate semantic and conceptual factors across the levels of the independent variables, referents were selected in quadruplets from the same semantic category. Nonwords were arbitrarily assigned to referents, and nonword-referent pairings were counterbalanced across participants.

Story. The 16 nonword-referent pairs were divided into two sets of 8, balancing both phonotactic constraints and phonotactic probability across sets. Two stories were created, each incorporating one of the sets of 8 nonword-referent pairs. Each story had three distinct episodes that focused on two main characters performing a routine that was likely to be familiar to young children (e.g., hiding objects). The set of 8 nonword-referent pairs were incorporated in each episode. To create the episodes, scenes from children's picture books (Mayer, 1993; Sendak, 1962) were combined and adapted to incorporate the novel object referents. Scene 1 of each episode presented the two main characters and the routine. Scenes 2-5 displayed the two main characters performing the routine with the novel objects. Within each scene, a pair of semantically related objects was presented (e.g., punch toy and cork gun). Scene 6 showed the conclusion of the routine.

A narrative was created to parallel the visual scenes described above (refer to appendix for example). Scene 1 was accompanied by introductory sentences that established the characters and the routine. The narrative for Scenes 2-5 presented the target nonwords. The sentences for each nonword in a semantic pair were virtually identical. This ensured that the syntactic difficulty was equivalent across the independent variables. The Scene 6 narrative consisted of concluding sentences that provided a brief delay between exposure and testing. Across episodes, the number of repetitions of each nonword varied with Episode 1 providing one exposure and Episodes 2 and 3 each providing three exposures. A female speaker recorded four versions of each of the two story narratives to accomplish the appropriate counterbalancing of nonword-referent pairings.

Measure of Learning. A picture-naming task was used to assess learning at five test points: 0 cumulative exposures (i.e., Baseline), 1 cumulative exposure (i.e., after Episode 1), 4 cumulative exposures (i.e., after Episode 2), 7 cumulative exposures (i.e., after Episode 3), and 1 week post-exposure (M = 7.5 days; SD = 2.4; range of 2-14 days). In this task, a picture of one of the object referents was presented, and the child attempted to name the object. Responses were phonetically transcribed and scored. A lenient scoring criterion was used to avoid floor effects. A response was scored as correct if it contained two correct phonemes in the correct word position (e.g., [beɪp] for /meɪp/). For nonwords beginning with OUT sounds, the child's typical substitutes for a given target, as revealed by the real word and nonword probes, were counted as "correct." For example, if a child typically substituted [w] for /r/, [wʌb] for /rʌd / would be counted as two phonemes correct (/rʌ/). A response was scored as a phonological error if it contained two of the three phonemes of a phonologically related stimulus (e.g., [meɪp] for /mæb/). Likewise, a response was scored as a semantic error if it contained two of three phonemes of a semantically related stimulus (e.g., [meɪp]-

candy machine for /gif/-candy machine). A response was scored as an unrelated error if it contained two of three phonemes of any other nonword stimulus (e.g., [meɪp]-candy machine for /gɔɪt/-pet). Finally, a response was scored as incorrect with no additional indication of error type if it was (1) a real word description or correlate of the picture (e.g., “gun” for the cork gun toy), (2) the semantic category of the item (e.g., “candy machine” for [meɪp]-candy machine), or (3) any other response that did not fit the previously described categories (e.g., [reɪb] for /meɪp/). The lexical status (i.e., real word versus nonword) of responses was not tracked.

Procedures

Each child participated in three to seven sessions. During the first session, the GFTA, the real word and nonword probes, and the hearing screening were administered (ASHA, 1997). The full real word probe administered to the PD group contained more items than the brief real word probe, requiring an additional session. The *Peabody Picture Vocabulary Test – 3* (Dunn & Dunn, 1997) and the *Expressive Vocabulary Test* (Williams, 1997) were administered in a following session. Children in the PD group required two additional sessions to complete the *Test of Early Language Development-3 (Hresko et al., 1999)* and the *Leiter International Performance Scale-R (Roid & Miller, 1997).*

The lexical acquisition task required three sessions. The order of administration of the two stories and the four versions of each story were randomized across children. All auditory stimuli were presented via a digital audio tape deck and table top speakers at a comfortable listening level. Baseline testing was conducted for each nonword prior to story exposure. Children were told “I want you to try and guess the names of these pictures.” The object referents were then shown and the child was encouraged to guess. After completing baseline testing, the child listened to the first story episode, which provided one exposure of each of the eight nonwords. The picture-naming task was then re-administered. The instructions to the child were modified from encouraging the child to guess to encouraging the child to remember the items from the story. The child then listened to the second story episode, which provided three exposures to all eight nonwords. The picture-naming task was re-administered. Finally, the child listened to a third story episode that provided three exposures to the nonwords, and then the picture naming task was re-administered.

Retention of first story nonwords was tested one week post-exposure (*M* = 8 days; *SD* = 2; range = 2-14 days). Following retention testing, the second story was administered, using the procedures described above. Retention of second story items was tested one week post-exposure (*M* = 7 days; *SD* = 2; range = 4-14 days).

Results

Reliability

Consonant-to-consonant transcription reliability was computed for 18% of the GFTA, real word and nonword probes, and picture naming responses. Transcription reliability was 94% (*SD* = 2) for real words and 93% (*SD* = 4) for nonwords. Scoring reliability for picture naming was computed for 16% of the sample and was 98% (*SD* = 2). Procedural reliability was computed for 16% of the participants and was 96% (*SD* = 4).

Accuracy Analysis

Proportion of correct responses collapsed across individual nonwords and across stories served as the dependent variable. These proportions were submitted to a 3 Group (PD vs. PM vs. AVM) x 2 Phonotactic Constraints (IN vs. OUT) x 2 Phonotactic Probability (common vs. rare) x 4 Exposures (1 vs. 4 vs. 7 vs. one week post) ANOVA with Huyhn-Feldt correction for sphericity for repeated measures (Huynh & Feldt, 1976). An effect size, partial eta squared (η_p^2), was computed for each independent variable. Interpretation of this effect size is similar to that of a partial correlation (see Young, 1993 for tutorial). Results showed a significant three-way interaction between Group, Phonotactic Constraints, and Phonotactic Probability, F (2, 65) = 3.67, p = 0.03, η_p^2 = 0.10. This interaction was further explored by performing separate ANOVAs for each group.

PD group. Two children in the PD group evidenced floor effects as defined by 0% accuracy in all conditions across all exposures. These children were retained in the analysis because floor effects minimize the difference across conditions, yielding a conservative hypothesis test. Proportion correct for children in the PD group was submitted to a 2 Phonotactic Constraints (IN vs. OUT) x 2 Phonotactic Probability (common vs. rare) x 4 Exposures (1 vs. 4 vs. 7 vs. one week post) repeated measures analysis of variance. There was a main effect of Phonotactic Constraints, F (1, 19) = 5.74, $p = 0.03$, $\eta_p^2 = 0.23$, and a significant three-way interaction, F (3, 57) = 3.47, $p = 0.02$, $\eta_p^2 = 0.16$. The three-way interaction was explored further by (1) examining the effect of Phonotactic Constraints and Exposure for common versus rare stimuli separately, using a 2 Phonotactic Constraints (OUT vs. IN) x 4 Exposures (1 vs. 4 vs. 7 vs. post) repeated measures ANOVA; (2) examining the effect of Phonotactic Probability and Exposure for IN versus OUT stimuli separately, using a 2 Phonotactic Probability (common vs. rare) x 4 Exposures (1 vs. 4 vs. 7 vs. one week post) repeated measures ANOVA. For both analyses, significant interactions involving exposure were further explored by comparing performance at baseline (i.e., 0 exposures) to performance at each level of exposure (i.e., 1, 4, 7, 1 week post), using paired t-tests and Bonferroni correction. The goal of this analysis was to determine when performance was greater than baseline, indicating significant learning.

Figure 1 shows the proportion of correct responses for IN versus OUT sounds in common (top panel) and rare sound sequences (bottom panel). For common sound sequences (top panel), there was a significant interaction between Phonotactic Constraints and Exposure, F (3, 57) = 4.25; p =0.01; $\eta_p^2 = 0.18$. Retrieval and production of common IN sound sequences was never significantly greater than baseline, all $t\ (19) < 1.50$, all corrected $p \geq 0.65$. In contrast, retrieval and production of common OUT sound sequences was significantly greater than baseline at the post exposure test, t (19) = 3.68; corrected $p = 0.008$. For rare sound sequences (bottom panel), there was a significant effect of Phonotactic Constraints, F (1, 19) = 5.49; p =0.03; $\eta_p^2 = 0.22$. Retrieval and production of rare OUT sound sequences was more accurate than rare IN sound sequences. Thus, relative to question 1 concerning the effect of phonotactic constraints, the PD group learned OUT sound sequences more rapidly than IN sound sequences. This effect varied over exposures for common sound sequences, but was consistent for rare sound sequences during immediate learning.

Figure 2 shows the proportion correct for common versus rare sound sequences in nonwords beginning with IN sounds (top panel) and nonwords beginning with OUT sounds (bottom panel). For IN sound sequences (top panel), there was a significant interaction between Phonotactic Probability and Exposure, F (3, 49) = 5.27; p =0.01; $\eta_p^2 = 0.22$. Recall that retrieval and production of common IN sound sequences was never significantly greater than baseline. In contrast, retrieval and production of rare IN sound sequences at the post exposure test approached significance, t (19) = 2.52; corrected p = 0.08. For OUT sound sequences (bottom panel), the main effect of Phonotactic Probability approached significance, F (1, 19) = 3.52; p =0.08; $\eta_p^2 = 0.16$. Recall that retrieval and production of common OUT sound sequences was significantly greater than baseline performance at the post exposure only. In contrast, retrieval and production of rare OUT sound sequences was significantly greater than baseline following 1, 4, and 7 exposures and at post exposure, all t *(19)* $\geq$ 2.98, all corrected $p \leq 0.03$. Thus, relative to question 2 concerning the effect of phonotactic probability, the PD group learned common sound sequences more slowly than rare sound sequences. This effect was apparent only at the post test for words beginning with IN sounds, but was consistent for words beginning with OUT sounds during immediate learning (i.e., 1, 4, and 7 exposures).

Relative to question 3 regarding the consistency of the effect of phonotactic probability across IN and OUT sound sequences, as previously noted a significant interaction between phonotactic constraints and phonotactic probability was obtained, but this appeared to be attributable to changes in the magnitude of the common sound sequence disadvantage across IN and OUT sounds and across exposures. Thus, the direction of the phonotactic probability effect (i.e., common sound sequence disadvantage) was consistent across IN and OUT sounds.

The PM group. Five children in the PM group demonstrated floor effects. For the PM group, there was a significant main effect of Phonotactic Probability, F (1, 23) = 7.61, p = 0.01, η_p^2 = 0.25, and a significant interaction between Phonotactic Constraints and Phonotactic Probability, F (1, 23) = 7.76, p = 0.01, η_p^2 = 0.25. This interaction was explored using the methods described above.

Figure 3 shows the proportion of correct responses for IN versus OUT sounds in common (top panel) and rare sound sequences (bottom panel). For common sound sequences (top panel), there was a significant effect of Phonotactic Constraints, F (1, 23) = 6.27; p =0.02; η_p^2 = 0.21. Retrieval and production of common OUT sound sequences was more accurate than common IN. For rare sound sequences (bottom panel), no effects were significant, all $F \leq 1.61$, all $p \geq 0.22$, all $\eta_p^2 \leq 0.07$. Thus, relative to question 1 concerning the effect of phonotactic constraints, the PM group learned OUT sound sequences more rapidly than IN, but this was only observed for common sound sequences.

Figure 4 shows proportion correct for common versus rare sound sequences for IN (top panel) versus OUT sounds (bottom panel). For IN sounds (top panel), the main effect and interactions were not significant, all $F \leq 2.16$; all $p > 0.11$; all $\eta_p^2 \leq 0.09$. For OUT sounds (bottom panel), there was a significant effect of Phonotactic Probability, F (1, 23) = 11.51; p =0.003; η_p^2 = 0.16. Common OUT sound sequences were retrieved and produced more accurately than rare OUT. Relative to question 2 concerning the effect of phonotactic probability, the PM group learned common sound sequences more rapidly than rare sound sequences, but this advantage was evident only for OUT sounds.

Relative to question 3 regarding the consistency of the effect of phonotactic probability across IN and OUT sound sequences, the previously described analysis showed no common sound sequenced advantage or disadvantage for IN sounds, but did show a significant common sound sequence advantage for OUT sounds. Like the PD group, the direction of the phonotactic probability effect across IN and OUT sounds was consistent for the PM group.

AVM group. No children in the AVM group demonstrated floor effects. For the AVM group, only the main effect of Exposure was significant, F (3, 54) = 7.70, p = 0.00, η_p^2 = 0.25. Phonotactic constraints and phonotactic probability did not appear to influence lexical acquisition by this group.

Error Analysis

Error responses were analyzed for the PD and PM groups to examine the status of mental representations. The AVM group was excluded because they failed to show significant effects in the accuracy analysis. Error analyses were performed only for responses at the 1-week post exposure for simplicity. Due to the observed group differences in accuracy, the PD and PM groups were analyzed independently. For each Phonotactic Constraints x Phonotactic Probability condition, the number of responses of a given type was divided by the total number of responses in that condition. In this way, "no response" trials were excluded. The four response types were: (1) correct; (2) phonological error; (3) semantic error; (4) unrelated error. Response Type was then analyzed for each Phonotactic Constraints x Phonotactic Probability condition for each group using a one-way ANOVA. In the case of significant effects, trends are described rather than pairwise comparisons due to lack of power. The goal of this analysis was to determine the predominant response type for each condition. As previously described, it was assumed that correct responses were indicative of a complete representation. Phonological errors were assumed to indicate a holistic lexical representation. Semantic errors were thought to result from a holistic semantic representation as well as difficulty creating appropriate associations between lexical and semantic representations. Unrelated errors were taken as evidence of deficits in the association between lexical and semantic representations with the identity of the substituted nonword providing evidence of the status of the lexical representation of that substitute.

PD group. For children in the PD group, significant effects were obtained. Figure 5 displays the proportion of response types by condition for the PD group. There was a significant effect of Response Type for common IN sound sequences, F (3, 57) = 8.25, p = 0.003, η_p^2 = 0.30. Here, the most frequent response type was unrelated errors followed by semantic errors. For rare IN sound sequences, there was no significant effect of Response Type, F (3, 57) = 0.65, p = 0.59, $\eta_p^2 = 0.03$. For common OUT sound sequences there was a significant effect of Response Type, F (3, 57) = 4.86, p = 0.01, $\eta_p^2 = 0.20$. Correct and unrelated error responses predominated. For rare OUT sound sequences, there was no significant effect of Response Type, F (3, 57) = 1.30, p = 0.29, $\eta_p^2 = 0.06$.

This analysis suggests that certain aspects of lexical acquisition were vulnerable to failure when children with PD were learning common sound sequences. In particular, common IN sound sequences tended to lack appropriate associations between lexical and semantic representations (i.e., unrelated errors) or tended to have holistic semantic representations associated with the incorrect lexical representation (i.e., semantic errors). Common OUT sound sequences were either intact (i.e, correct responses) or lacked appropriate associations between lexical and semantic representations (i.e., unrelated errors). These findings suggest difficulty creating associations between lexical and semantic representations for common sound sequences. To further examine the status of lexical representations, the phonotactic constraints and phonotactic probability of unrelated substitutes were examined. Figure 6 shows the phonotactic constraints and phonotactic probability of the substitutes. The PD group infrequently produced common OUT sound sequences as substitutes for unrelated targets, suggesting that the lexical representations of common OUT sound sequences were impoverished. All other sound sequences were produced as substitutes, suggesting an emerging lexical representation.

The PM group. In all four conditions, there was no significant effect of Response Type for the PM group, all F (3, 69) $\leq$ 2.28, $p \geq 0.10$, $\eta_p^2 \leq 0.09$.

Discussion

The purpose of this study was to examine the effect of phonotactic constraints and phonotactic probability on lexical acquisition by children with PD. Moreover, the interaction between phonotactic constraints and phonotactic probability was investigated to determine the nature of the lexical representation of words composed of OUT sounds. Interpretations of main effects will be considered first, followed by discussion of interactions.

Phonotactic Constraints

Both the PD and younger PM groups showed a significant OUT sound sequence advantage at certain points, and neither group showed a significant IN sound sequence advantage at any test point. Specifically, for the PD group, the OUT advantage for common sound sequences was significant only at the post exposure test, whereas the OUT advantage for rare sound sequences was consistent across exposures during immediate learning. For the PM group, the OUT advantage was significant for common sound sequences but not for rare. This suggests that phonotactic constraints do continue to influence lexical acquisition in children who have surpassed the 50-word stage and that this influence is not dependent on the status of phonological development. Importantly, the direction of the influence of phonotactic constraints on lexical acquisition in this study was reversed from previous studies showing an IN sound sequence advantage (Leonard et al., 1981; Schwartz & Leonard, 1982).

Notably, the AVM group did not show an effect of phonotactic constraints. This serves as a necessary control condition because the AVM group correctly articulated all of the nonwords, failing to exhibit any relevant phonotactic constraints. Because these children did not show an effect of phonotactic constraints whereas the other two groups did, it can be argued that the effect of phonotactic constraints was crucially tied to the status of the sound as IN versus OUT in a given child's phonology, rather than to the specific identity of the sound. That is, it is not the case that /r/ and /θ/ words were inherently easier to learn than /m/ and /g/ words, but rather that words beginning with OUT sounds were learned more rapidly than words beginning with IN sounds.

While it appears that phonotactic constraints continue to influence lexical acquisition beyond the 50-word stage, it is unclear why the effect of phonotactic constraints would be reversed in more mature word learners. One possibility is that the effect of phonotactic constraints may be tied to salience. That is, early in development, words that match the child's phonology may be more salient than those that do not. This salience, in turn, may facilitate lexical acquisition. In contrast, later in development, violations of a child's phonotactic constraints may make the offending sound sequence more salient for the child. In this way, salience may change over time based on the relative number of IN versus OUT sounds. Specifically, early in development IN sounds may be salient because there are fewer IN sounds than OUT sounds, whereas later in development OUT sounds may be salient because there are fewer OUT sounds than IN sounds. Under this scenario, the influence of phonotactic constraints on lexical acquisition is viewed as being dependent on the relative number of IN versus OUT sounds (see Vihman & Nakai, 2003 for similar arguments related to familiarity vs. novelty).

A second possibility relates to methodological differences across the studies of younger and older children. In previous studies of younger children, OUT sounds were based on 0% accuracy and no occurrences of the sound. In this study of older children, OUT sounds were allowed to be more accurate. Thus, it is possible that the younger children in previous studies may have had relatively little knowledge of OUT sounds, whereas the children in this study may have had limited or emerging knowledge of OUT sounds. The difference in results across studies may be reconciled by examining the effect of phonotactic constraints on lexical acquisition from a perspective that views knowledge of sounds on a continuum from "least" to "most" (see Gierut, Elbert, & Dinnsen, 1987). The influence of phonotactic constraints on lexical acquisition may vary by the type of knowledge the child has acquired about a given sound. In this way, we might take the rate of learning of words containing most knowledge sounds as the baseline rate of lexical acquisition. Then, it might be assumed that least knowledge may inhibit lexical acquisition relative to this baseline, as shown for young children in previous studies, and relatively more knowledge may facilitate lexical acquisition, as shown for children in this study. This implies that the function describing the relationship between phonological knowledge and lexical acquisition is U-shaped such that least phonological knowledge is associated with slow lexical acquisition, intermediate knowledge is associated with rapid lexical acquisition, and most knowledge is associated with an intermediate rate of lexical acquisition.

Phonotactic Probability

The effect of phonotactic probability on lexical acquisition varied across groups with each group demonstrating a different pattern. The PD group showed a common sound sequence disadvantage at certain points (i.e., for IN sounds at post test and for OUT sounds at immediate learning tests) and never showed a significant common sound sequence advantage. In contrast, the younger PM group showed a common sound sequence advantage at certain points (i.e., for OUT sounds) and never showed a significant common sound sequence disadvantage, paralleling findings from previous studies (Storkel, 2001, 2003; Storkel & Rogers, 2000). The AVM group evidenced yet a third pattern of performance. This group learned common and rare sound sequences at equivalent rates. Importantly, these groups were matched on various characteristics, yet three distinct patterns of lexical acquisition were obtained. Thus, the effect of phonotactic probability on lexical acquisition was not solely determined by productive phonology or age/vocabulary.

Error analyses demonstrated different effects of phonotactic probability on the formation of representations across groups. For children with PD, the formation of certain types of representations was more vulnerable when learning common sound sequences. Specifically, children with PD appeared to be able to create a lexical representation for common IN sound sequences but may have had difficulty forming an association between this lexical representation and the corresponding semantic representation. Children with PD also seemed to have difficulty creating a lexical representation for common OUT sound sequences. In contrast, no differences in error rates were observed across common and rare sound sequences for the younger PM group.

Taken together, these results indicate that phonotactic probability does not influence lexical acquisition by children with PD in the same way as younger typically developing phonology-matched children (i.e., PM group). The effect of phonotactic probability on lexical acquisition by children with PD is suggestive of lexical competition such that the formation of a unique lexical representation is particularly vulnerable to failure when the novel sound sequence is common and thus similar to many other known words. In complement, creation of a unique lexical representation for novel rare sound sequences was less prone to failure as would be expected because these sound sequences are similar to few other known words. In contrast, the effect of phonotactic probability on lexical acquisition by children in the PM group is suggestive of phonological facilitation such that common sound sequences facilitate phonological processing speeding lexical acquisition.

What remains less clear is why this difference between the PD and PM groups exists. One possibility is that children with PD may rely more heavily on lexical representations to support lexical acquisition, whereas typically developing children may rely more heavily on phonological representations to support lexical acquisition. This might be attributable to underlying differences in the quality of phonological representations between children with PD and typically developing children. That is, phonological representations and processing in children with PD may not be developed enough to support lexical acquisition, resulting in a greater reliance on lexical representations and processing for this group. An alternative possibility is that both groups may rely equally on phonological or lexical representations but the factor that differentiates the groups is the effect of phonological similarity. The children with PD may have had difficulty differentiating phonologically similar items leading to confusion between the common novel sound sequences and other known sound sequences. In this way, the high degree of phonological similarity inherent in learning a common sound sequence may have inhibited lexical acquisition. The children with PM may have been able to distinguish common novel sound sequences from other known sound sequences, and then the similarity between novel and known sound sequences may have facilitated acquisition. This hypothesis is in keeping with previous claims that the lexical representation of a new common sound sequence is likely to form associations with many other existing lexical representations and that this connectivity may help strengthen the new representation, speeding acquisition (Storkel, in press).

The AVM group appeared to learn both common and rare sound sequences equally. This lack of an effect of phonotactic probability differs from previous studies of children in this age range (Storkel, 2001, 2003). One discrepancy between this study and previous ones is the higher degree of phonological similarity during the exposure phase of the study. Previous studies documenting a common sound sequence advantage in children this age have selected the nonword stimuli so that each nonword was dissimilar from every other, with few repeated phonemes across nonwords. Because of the need to control phonotactic constraints across children in this study, the same set of word-initial phonemes had to be used repeatedly, leading to a higher degree of phonological similarity. In this way, phonological similarity may have obscured the effect of phonotactic probability on lexical acquisition.

Interaction between Constraints and Probability

A significant interaction between phonotactic constraints and phonotactic probability was obtained for the two groups of children who exhibited phonotactic constraints, namely the PD group and the PM group. Importantly, this interaction did not appear to reverse the direction of the effect of phonotactic probability (i.e., common sound sequence advantage vs. disadvantage) but rather increased or reduced the size of the effect. Thus, the effect of phonotactic probability (i.e., common sound sequence advantage vs. disadvantage) based on the target adult pronunciation was similar across IN and OUT sounds. This finding suggests that the lexical representation of words beginning with either IN or OUT sounds is based on the adult pronunciation for both the PD and PM groups. In other words, the lexical representation of misarticulated words appeared to be target appropriate for both groups.

The finding of target appropriate lexical representations for words beginning with OUT sounds does not necessarily assume that these representations are adult-like. There is ongoing controversy concerning whether the lexical representation of known words changes over time. Some have argued that lexical representations are segmentally detailed or adult-like early in acquisition (e.g., Bailey & Plunkett, 2002; Dollaghan, 1994; Swingley & Aslin, 2000, 2002), whereas others argue that lexical representations may be holistic initially, gradually becoming segmentally detailed or adult-like (e.g., Charles-Luce & Luce, 1990, 1995; Jusczyk, Goodman, & Baumann, 1999; Metsala & Walley, 1998; Storkel, 2002). The current findings do not support or refute either of these claims, but merely suggest that the lexical representation of words composed of OUT sounds is based on the adult target.

Interactions with Exposure

Although there were no a priori questions related to interactions with exposure, results showed group differences in the presence of these interactions which warrant comment. The PD group showed significant interactions involving exposure, whereas the PM group did not. For the PD group, responses to rare OUT sound sequences were significantly above baseline following just 1 exposure. In contrast, responses to rare IN sound sequences and common OUT sound sequences did not approach or achieve a significant difference from baseline until post exposure. Finally, responses to common IN sound sequences were never significantly above baseline. In this way, the words that had advantageous values for both phonotactic constraints (i.e., OUT) and phonotactic probability (i.e., rare) were learned with few exposures. The words that had advantageous values for only one variable, either phonotactic constraints or phonotactic probability, required more exposures. The words that had disadvantageous values for both phonotactic constraints and phonotactic probability were never learned.

The younger PM group showed no significant interactions involving exposure in any of the analyses. For this reason, follow-up analyses of the effect of exposure were not reported for the PM group, however, inspection of Figures 3 and 4 indicates that responses to Common OUT sound sequences were above chance following just 1 exposure and this was confirmed through statistical analysis, all t (23) >-2.93, all corrected $p < 0.03$. Performance for common IN, rare IN and rare OUT sound sequences was never significantly different from baseline, all t (23) < -2.60, all corrected $p >$ 0.05; yet, inspection of Figure 3 indicates that accuracy of common IN sound sequences was similar to that of common OUT sound sequences at the post exposure test. For the PM group, words with advantageous values for both phonotactic constraints and phonotactic probability were learned following few exposures, and words with disadvantageous values for both phonotactic constraints and phonotactic probability were never learned. Differences between the PD and PM group were noted for the words that had advantageous values for only one variable. Here, the PM group showed significant learning of words with advantageous values for only phonotactic probability by post-test, whereas words with an advantageous value for only phonotactic constraints never showed significant learning. In contrast, the PD group showed significant learning for both of these types of word by post-test. This may indicate that phonotactic probability exerts a stronger influence on lexical acquisition than phonotactic constraints for the PM group, whereas phonotactic probability and phonotactic constraints may exert an equivalent influence on lexical acquisition by the PD group.

Clinical Implications

These findings have several clinical implications. One relates to the possibility that the composition of the lexicon of children with PD may differ from that of typically developing children. Children with PD may have lexicons that are composed of many words that are similar to only a few other words in the language (i.e., rare sound sequences). In contrast, the lexicon of typically developing children may be composed of many words that are similar to many other words in the language (i.e., common sound sequences). This is relevant because it has been suggested that similarity to other words in the language may promote changes in lexical representations that then give rise to phonological awareness (e.g., Metsala & Walley, 1998; Walley, Metsala, & Garlock, 2003). If children with PD are slower to learn phonologically similar words, then they may be at risk for later phonological awareness deficits. Indeed, a higher incidence of poor phonological awareness has been observed in children with a history of phonological delay (e.g., Hesketh, Adams, Nightingale, & Hall, 2000; Webster & Plante, 1992). Future work is needed to examine the composition of the lexicon of children with PD and its association with the development of phonological awareness.

A second clinical issue relates to whether this difference in the effect of phonotactic probability on lexical acquisition resolves once delays in productive phonology have been remediated. At the heart of this question is whether this difference in the effect of phonotactic probability on lexical acquisition is due to delays in the acquisition of productive phonology or attributable to a more general processing difference. If the difference in the effect of phonotactic probability is attributable to productive phonology, then a common sound sequence advantage in lexical acquisition should emerge when productive phonology improves to an age-appropriate level. In contrast, if the difference in the effect of phonotactic probability is due to a more general processing difference, then a common sound sequence disadvantage may continue after the delay in productive phonology has resolved. If this is the case, then these children may be at risk for other types of language acquisition deficits. Future work is needed to more fully document the phonological and lexical processing abilities of children with PD.

Conclusion

Comparison of lexical acquisition by typically developing children and children with PD provided evidence of similarities and differences. Both groups showed a significant effect of phonotactic constraints on lexical acquisition with an advantage observed for words composed of OUT sounds. This result was taken as evidence of a shift in the salience of IN versus OUT sounds across development. For both groups, the direction of the effect of phonotactic probability on lexical acquisition was consistent across IN and OUT sounds, providing evidence that the lexical representation of misarticulated words was based on the adult target, rather than the child's surface production. Important differences between typically developing children and children with PD also were revealed. Specifically, the direction of the effect of phonotactic probability on lexical acquisition varied across groups. Typically developing children showed common sound sequence advantage in whereas children with PD showed common sound sequence disadvantage, with particular difficulty noted in the formation of lexical representations and associations between lexical and semantic representations. This result indicates the need to more closely examine phonological and lexical processing and representations in children with PD.

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Appendix. Sample story episode.

Episode 1	Story 1		Story 2	
	Scene	Narrative	Scene	Narrative
Scene 1	Girl monster character sitting on floor next to couch crying. Boy monster character standing next to couch.	Mom and dad were at work. Big Brother had to take care of Little Sister. Little Sister was crying. “I’ll take you to the park if you stop crying,” said Big Brother.	Girl crocodile character talking and boy crocodile character listening.	Mary and Joe crocodile had to go to school. Today was a big day. It was show and tell day. Mary and Joe were looking for things to bring.
Scene 2	Boy character dancing with red candy + 1 chute in thought cloud. Girl character dancing with blue candy + 2 chutes in thought cloud.	“We can go to the candy machines at the park,” said Big Brother. “My favorite is the /rʌd/.” Little Sister said, “My favorite is the /θoʊm/.	Girl character dancing with yellow candy + 1 chute in thought cloud. Boy character dancing with green candy + 1 chute in thought cloud.	“We can stop at the candy machines on the way to school,” said Mary. “My favorite is the /gif/.” Joe said, “My favorite is the /meɪp/.
Scene 3	Boy character standing and holding punch toy. Girl character sitting and holding cork gun.	“Can we bring some toys?” asked Little Sister. “Yes,” said Big Brother. “I’m bringing my /θaɪp/.” Little Sister said, “I’m bringing my /gaʊb/.”	Girl character standing and holding punch arrow. Boy character standing and holding marshmallow sprayer.	“Can we bring some toys?” asked Joe. “Yes,” said Mary. “I’m bringing my /mɑt/.” Joe said, “I’m bringing my /rim/.”

Scene 4	Boy character standing blowing on orange trumpet with bell pointing down. Girl character in profile blowing on yellow hand-held tuba.	"We can play music at the park," said Big Brother. "I'm taking my /maɪd/." Little Sister said, "I'm taking my /rup/."	Girl character in profile blowing on red saxophone pointing down. Boy character in profile blowing blue oboe pointing up.	"We can play music at show and tell," said Mary. "I'm taking my /θæb/." Joe said, "I'm taking my /ɡʌd/."
Scene 5	Boy character walking green gerbil with antenna on a leash. Girl character carrying purple mouse-bat.	"What about the pets?" asked Little Sister. "We'll take them with us," said Big Brother. "I'll get /ɡɔɪt/." Little Sister said, "I'll get /mæb/."	Girl character holding yellow frog bat. Boy character walking orange elephant-mouse on leash.	"Can we bring our pets?" asked Joe. "Sure," said Mary. "I'll get /roʊf/." Joe said, "I'll get /θum/."
Scene 6	Boy and girl character running down a sidewalk with arms in the air.	"Let's go!" said Big Brother. "Yea!" said Little Sister. They ran all the way to the park. What will they do at the park?	Boy and girl character seated in a car with father character driving.	"Let's go!" said Mary. "Yea!" said Joe. They climbed in the car to go to school. What will the other kinds think of their stuff?

Note. There were three additional alternative versions of this story episode to achieve counterbalancing in pairing nonwords with referents across participants.

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Table 1

Participant Standardized Test Performance and Production Probe Accuracy

	PD Group	PM group	AVM group
Gender	15 Males; 5 Females	13 Males; 11 Females	9 Males; 15 Females
PPVT-3 Standard Score[a]	105 (11)	106 (13)	112 (10)
EVT Standard Score[b]	105 (10)	107 (10)	112 (12)
GFTA-2 Percentile[c]	10 (6)	41 (17)	76 (17)
TELD-3 Standard Score[d]	103 (14)	N/A	N/A
Leiter-R Brief IQ[e]	116 (16)	N/A	N/A
Age (in months)	$60\ (9)_a$	46 (8)	$57\ (10)_a$
/m/ accuracy			
real words	$100\ (0)_a$	$100\ (0)_a$	$100\ (0)_a$
nonwords	$99\ (4)_a$	$100\ (2)_a$	$100\ (0)_a$
/g/ accuracy			
real words	$96\ (10)_a$	$99\ (3)_a$	$100\ (0)_a$
nonwords	$99\ (4)_a$	$100\ (0)_a$	$100\ (0)_a$
/r/ accuracy			
real words	$2\ (6)_a$	$4\ (10)_a$	97 (7)
nonwords	$0\ (0)_a$	$6\ (21)_a$	99 (4)
/θ/ accuracy			
real words	13 (18)	3 (10)	89 (11)
nonwords	$6\ (16)_a$	$6\ (13)_a$	95 (7)
PPVT-3 Raw Score[a]	$71\ (17)_a$	56 (18)	$77\ (16)_a$
EVT Raw Score[b]	$54\ (9)_a$	44 (8)	$57\ (11)_a$

Note. Standard deviations are in parentheses. Means in the same row that share subscripts do not differ significantly in a t-test comparison (i.e., $p > 0.15$), suggesting matching.

[a] *Peabody Picture Vocabulary Test-3.* [b] *Expressive Vocabulary Test.* [c] *Goldman-Fristoe Test of Articulation-2.* [d] *Test of Early Language Development.* [e] *Leiter International Performance Scale-R.*

Table 2.

Phonotactic probability of the nonwords in each condition.

	Adult target pronunciation		Child surface pronunciation	
	Positional segment frequency	Biphone frequency	Positional segment frequency	Biphone frequency
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Common In	0.1498 (0.03)	0.0078 (0.0038)	N/A	N/A
Rare In	0.0993 (0.07)	0.0014 (0.0053)	N/A	N/A
Common Out	0.1218 (0.01)	0.0040 (0.0011)	0.0920 (0.01)	0.0019 (0.0002)
Rare Out	0.0936 (0.02)	0.0022 (0.0005)	0.1513 (0.03)	0.0050 (0.0017)

Note. For nonwords beginning with IN sounds, the adult target pronunciation and child surface pronunciation are synonymous.

Table 3

Form and Referent Characteristics of the Stimuli

IN		OUT		Category	Referent 1	Referent 2	Referent 3	Referent 4
Common	Rare	Common	Rare					
meɪp	gif	rʌd	θoʊm	Candy Machine	Red candy + 1 chute (created)	Blue candy + 2 chutes (created)	Yellow candy + 1 chute (created)	Green candy + 1 chute (created)
mæb	gɔɪt	roʊf	θum	Pet	Green gerbil + antenna (DeBrunhoff, 1981)	Purple mouse-bat (Mayer, 1992)	Yellow frog-bat (Mayer, 1992)	Orange elephant mouse (Mayer, 1992)
maɪd	gʌd	rup	θæb	Horn	Orange trumpet bell pointing down (Geisel & Geisel, 1954)	Yellow hand-held tuba (Geisel & Geisel, 1954)	Red saxophone pointing down (Geisel & Geisel, 1954)	Blue oboe pointing upward (Geisel & Geisel, 1954)
mɑt	gaʊb	rim	θaɪp	Toy	Punch toy (Geisel & Geisel, 1958)	Cork gun (Geisel & Geisel, 1958)	Punch arrow (Geisel & Geisel, 1958)	Marshmallow sprayer (Geisel & Geisel, 1958)

Note. Nonwords transcribed using the International Phonetic Alphabet. Phonotactic probability based on adult target pronunciation.

Figure Captions

Figure 1. Mean proportion of correct responses by the PD group for IN vs. OUT sounds following 0, 1, 4, 7, and 1-week post exposure. Top panel shows common sound sequences and bottom shows rare sound sequences. Error bars represent standard errors. Chance performance is referenced by 0 exposures (baseline).

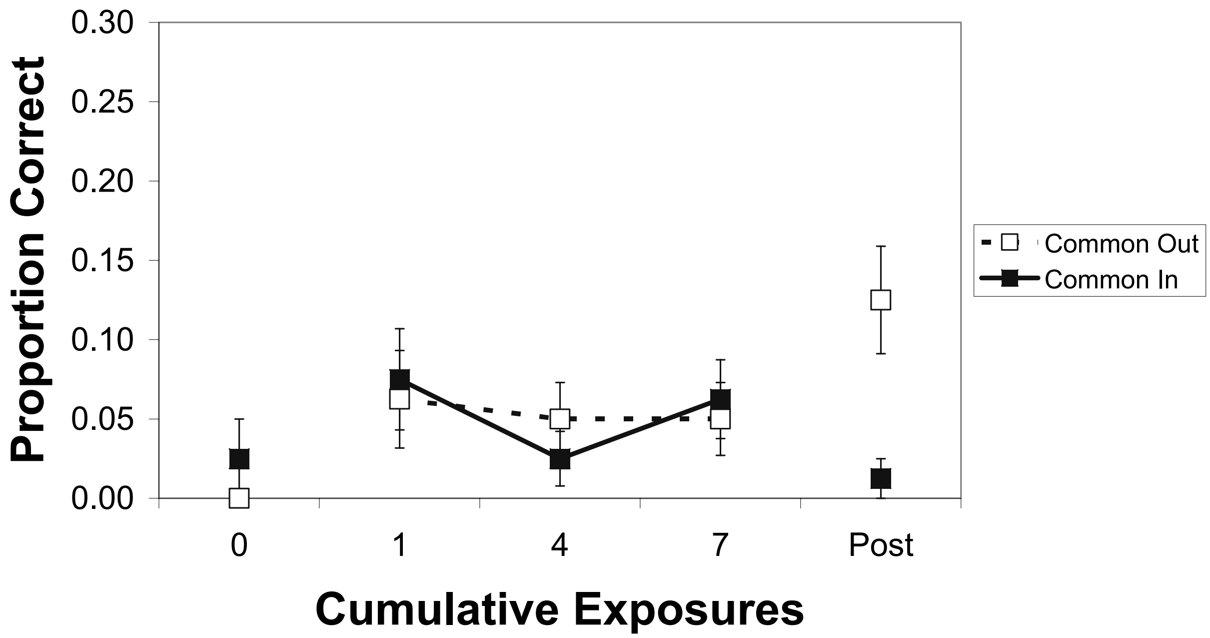
Figure 2. Mean proportion of correct responses by the PD group for common vs. rare sound sequences following 0, 1, 4, 7, and 1-week post exposure. Top panel shows IN sound sequences and bottom shows OUT sound sequences. Error bars represent standard errors. Chance performance is referenced by 0 exposures (baseline).

Figure 3. Mean proportion of correct responses by the PM group for IN vs. OUT sounds following 0, 1, 4, 7, and 1-week post exposure. Top panel shows common sound sequences and bottom shows rare sound sequences. Error bars represent standard errors. Chance performance is referenced by 0 exposures (baseline).

Figure 4. Mean proportion of correct responses by the PM group for common vs. rare sound sequences following 0, 1, 4, 7, and 1-week post exposure. Top panel shows IN sound sequences and bottom shows OUT sound sequences. Error bars represent standard errors. Chance performance is referenced by 0 exposures (baseline).

Figure 5. Mean proportion of each response type by the PD group for each Phonotactic Constraints x Phonotactic Probability condition at 1 week post exposure. Error bars represent standard errors.

Figure 6. Mean proportion of nonwords produced as unrelated substitutes by the PD group at 1 week post exposure. The Phonotactic Constraints and Phonotactic Probability of the substituted nonword are indicated. Error bars represent standard errors.



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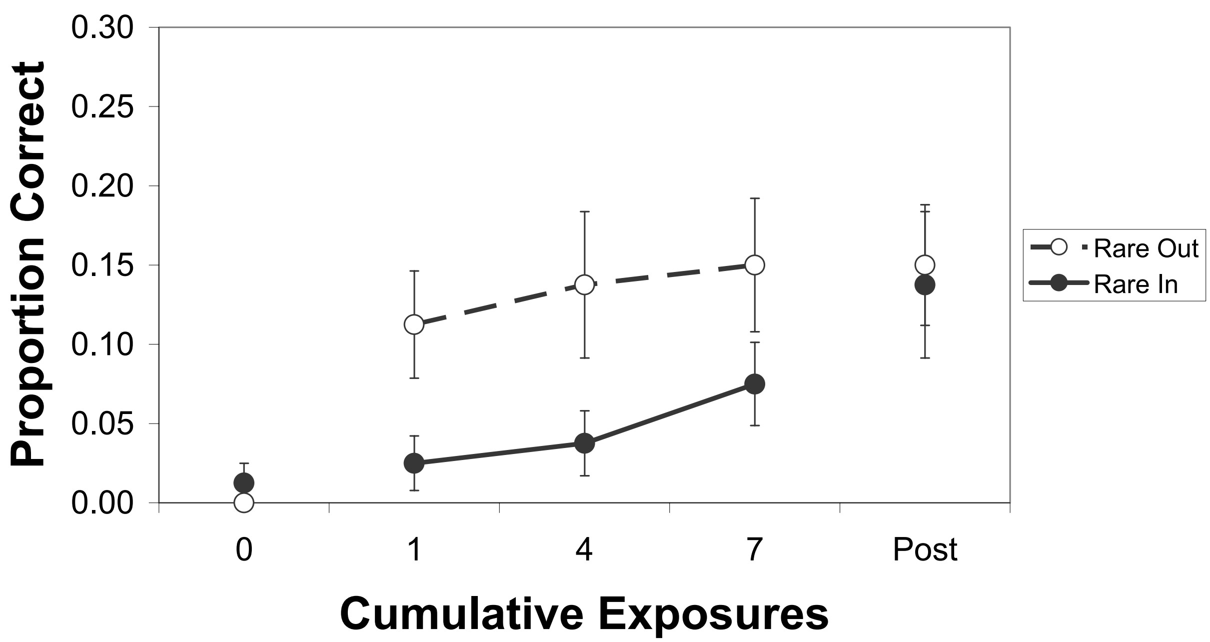

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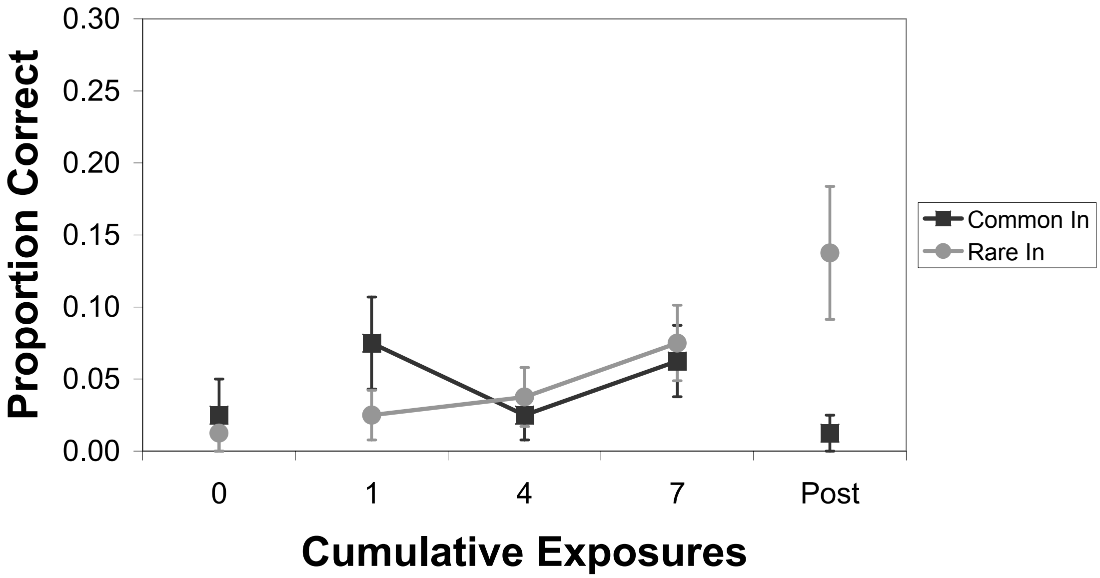
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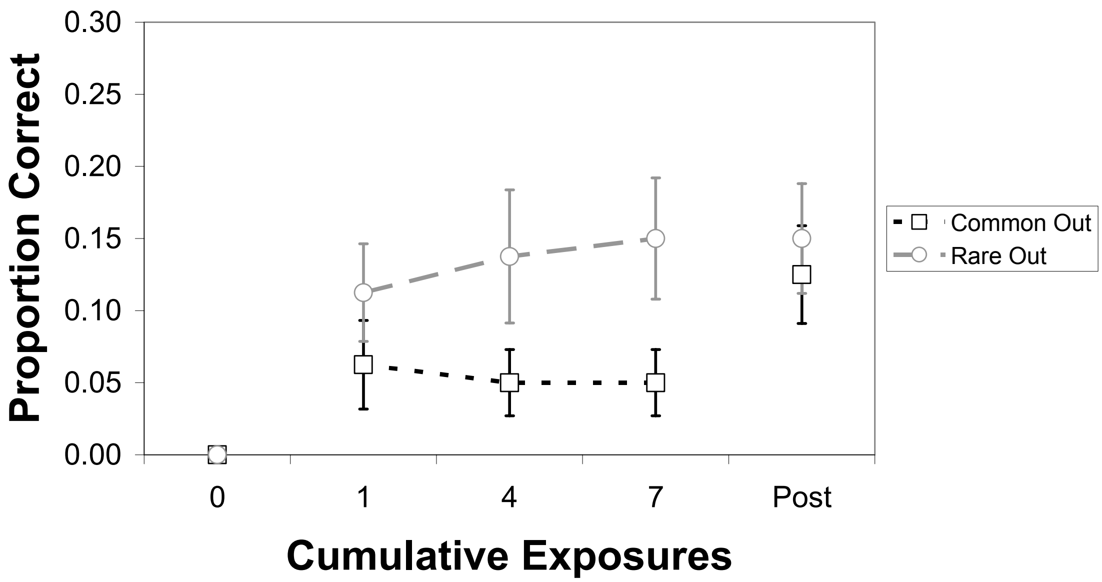
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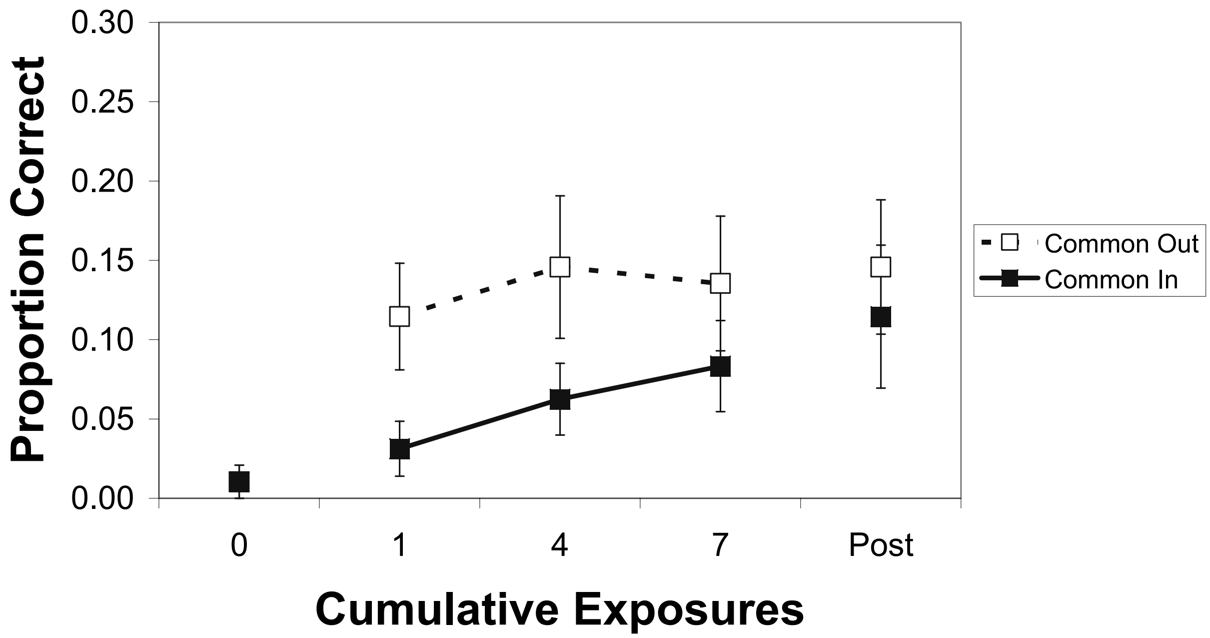
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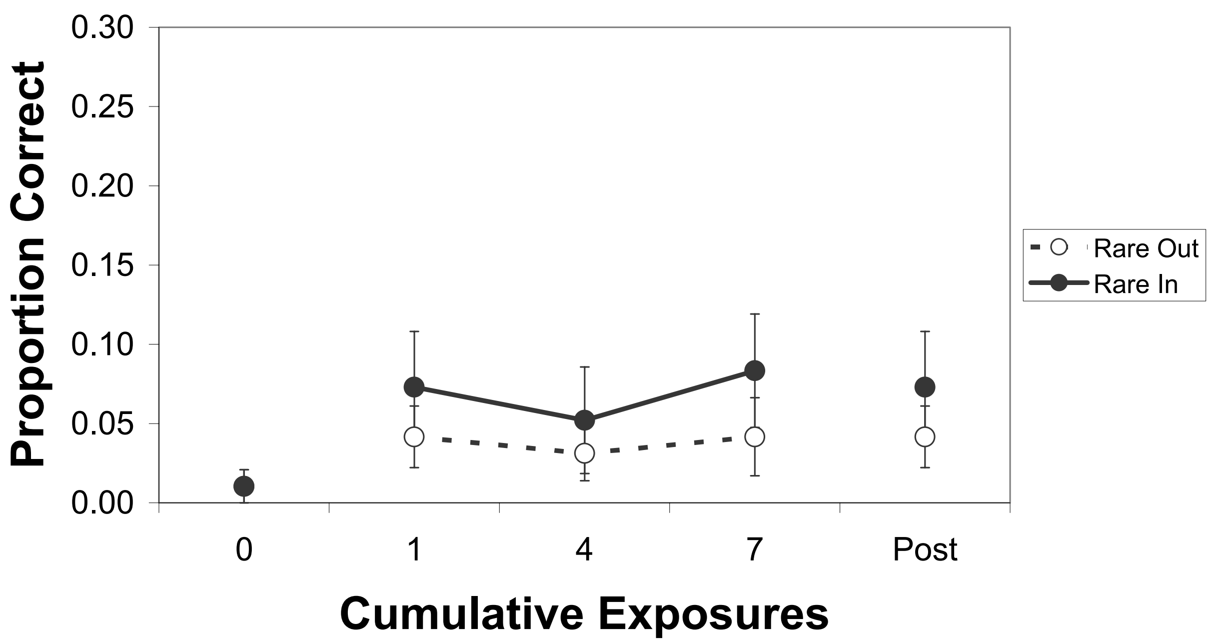
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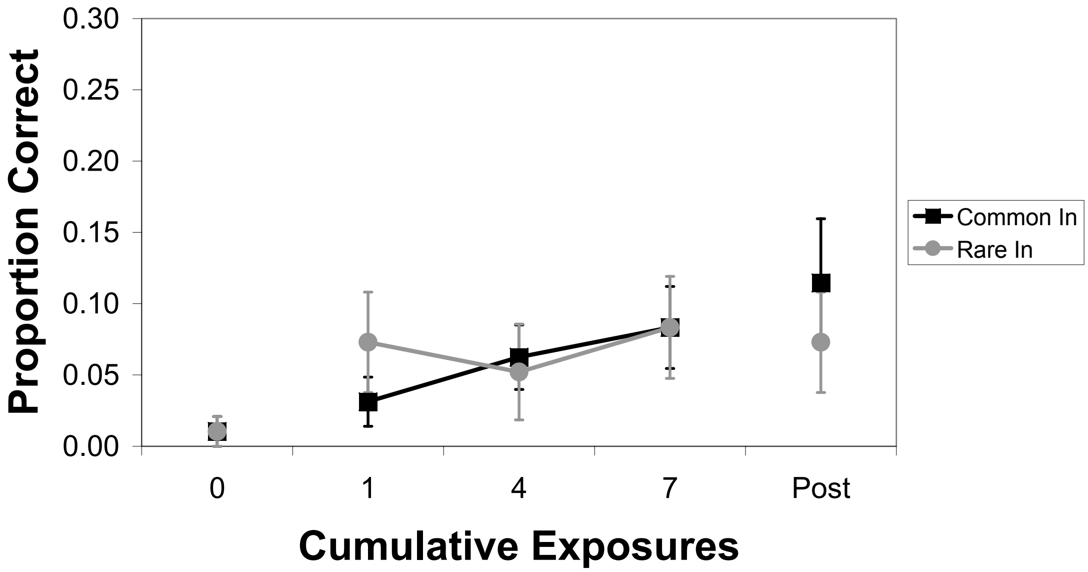
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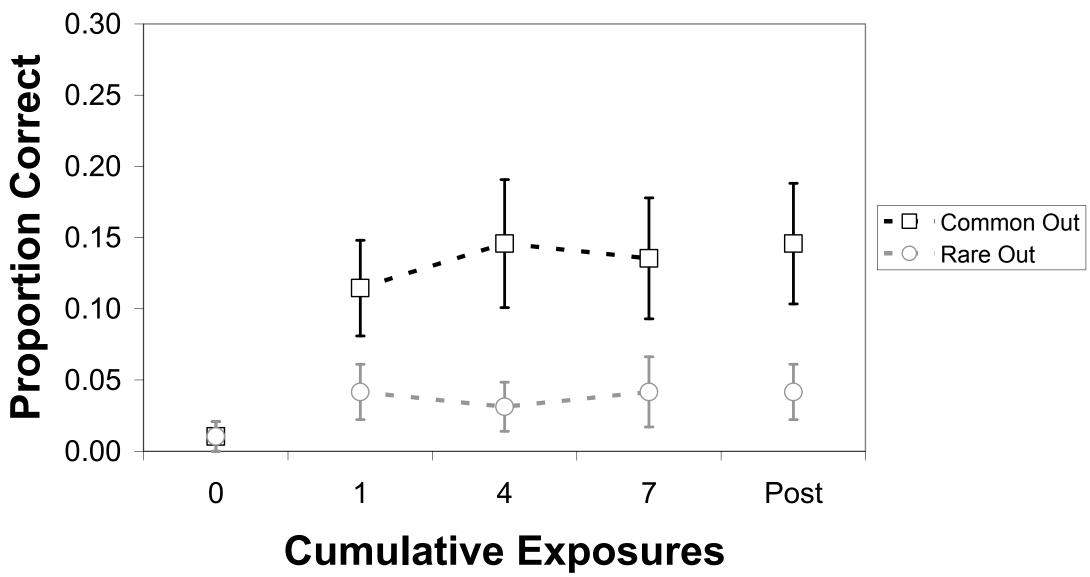
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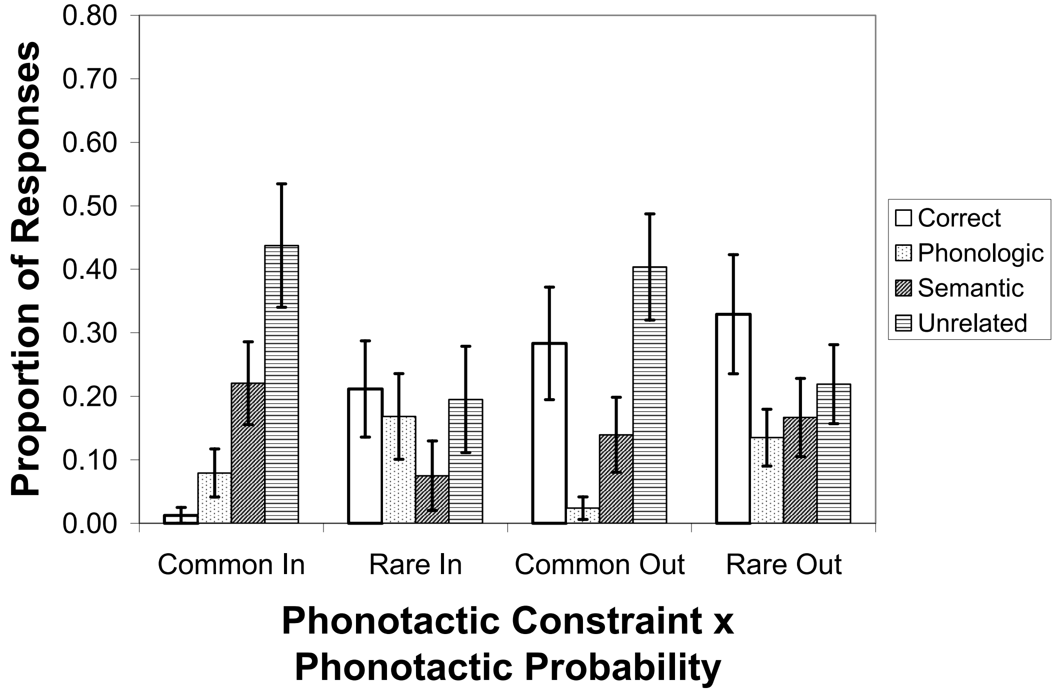
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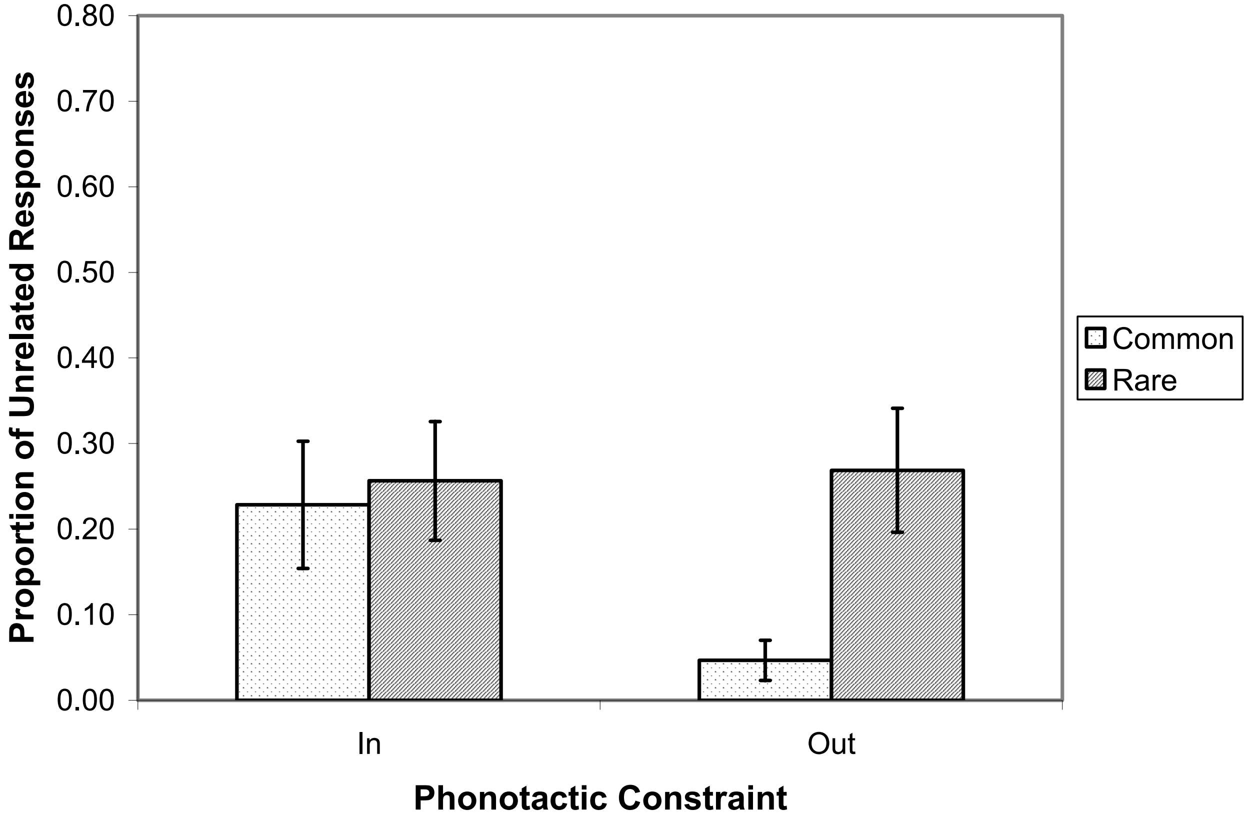
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