Learning New Words: Phonotactic Probability in Language Development

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Abstract

While the influences of syntactic and semantic regularity on novel word learning are well documented, considerably less is known about the influence of phonological regularities on lexical acquisition. The influence of phonotactic probability, a measure of the likelihood of occurrence of a sound sequence, on novel word learning is investigated in this study. Thirty-four typically developing children (3; 2-6; 3) participated in a multi-trial word learning task involving nonwords of varying phonotactic probability (common vs. rare) paired with unfamiliar object referents. Form and referent learning were tested following increasing numbers of exposures (1 vs. 4 vs. 7) and following a 1-week delay. Correct responses were analyzed to determine whether phonotactic probability affected rate of word learning, and incorrect responses were analyzed to examine whether phonotactic probability affected the formation of semantic representations, lexical representations, or the association between semantic and lexical representations. Results indicated that common sound sequences were learned more rapidly than rare sound sequences across form and referent learning. In addition, phonotactic probability appeared to influence the formation of semantic representations and the association between semantic and lexical representations. These results are integrated with previous findings and theoretical models of language acquisition.

Learning New Words: Phonotactic Probability in Language Development

Children have an amazing ability to rapidly acquire novel words, as revealed in both experimental and naturalistic studies of word learning. Experimental studies have shown that children associate the phonological properties, or form, of a novel word with its referent after just one exposure (Dickinson, 1984; Dollaghan, 1985; 1987; Heibeck & Markman, 1987). This ability to create associations between forms and referents with minimal exposure has been termed fast mapping (Carey & Bartlett, 1978). Likewise, children are able to learn novel words encountered in discourse where fewer cues are available to facilitate the matching of form to referent (Oetting, Rice, & Swank, 1995; Rice, Buhr, & Nemeth, 1990; Rice & Woodsmall, 1988). This ability has been termed quick incidental learning (QUIL; Rice, 1990). These skills apparently allow children to efficiently build a lexicon, supporting acquisition of as many as nine words per day in a naturalistic setting (Bloom, 1973; Clark, 1973; Nelson, 1973; Templin, 1957).

While it has been firmly established that children have a remarkable capacity to acquire new words, the underlying mechanisms allowing children to accomplish this is less clear. Two theories of word learning, constraint and associationistic, provide possible explanations with corresponding support from experimental studies. Constraint theories propose that children rely on cognitive constraints or principles to guide word learning (Clark, 1983; Golinkoff, Mervis, & Hirsh-Pasek, 1994; Markman, 1989; Markman & Hutchinson, 1984; Markman & Wachtel, 1988; Merriman & Bowman, 1989; Waxman & Kosowski, 1990). These constraints supposedly narrow the possible interpretations of a word. For example, a child might learn that novel words tend to refer to a whole object, rather than to a part or an attribute of an object (Markman & Wachtel, 1988). This constraint then restricts the possible referents of a new word. Presumably, constraints facilitate word learning because the child need not consider all possible interpretations of a novel word, leading the child to focus on the most likely interpretation. These theories suggest that rapid word learning is attributable to the development of specialized word learning constraints.

A second perspective is offered by associationistic theories. Associationistic theories assume that children are sensitive to co-occurrences in the language (Plunkett, 1997; Samuelson & Smith, 1998; Smith, 1995; 1999; Smith, Jones, & Landau, 1996). For example, one characteristic of count nouns, such as “car,” is that all the exemplars tend to be similar in shape (Biederman, 1987; Rosch, 1978). Children appear to learn this association as evidenced by their extension of novel count nouns to objects that are similar in shape to the original object (Jones, Smith, & Landau, 1991). Thus, through experience with the ambient language, children appear to learn the regularities of the language and capitalize upon these to support word learning. This is also the foundation for the concept of “bootstrapping.” Claims about bootstrapping assume that children rely on cues that co-occur with words to support lexical acquisition. Semantic (e.g., Grimshaw, 1981; Pinker, 1984), prosodic (e.g., Cassidy & Kelly, 1991; Cutler & Carter, 1987; Morgan, 1986) and syntactic cues (e.g., Gleitman, 1990; Gleitman & Gleitman, 1992; Landau & Gleitman, 1985) have been identified. According to associationistic theories, rapid word learning is the result of general attentional mechanisms that are attuned to regularities in the ambient language.

Past work from each of these perspectives has focused primarily on semantic, syntactic, and prosodic regularities that may be harnessed to support word learning (but see Bird & Chapman, 1998; Leonard, Schwartz, Morris, & Chapman, 1981; Schwartz & Leonard, 1982). In this study, we seek to extend these theories of word learning by considering the influence of regularities in segmental phonology. In particular, certain phonotactically legal sound sequences are more likely to occur than others. This likelihood of occurrence has been termed phonotactic probability. Words of the language can be divided into those that have relatively common sound sequences versus those that have relatively rare sound sequences. A common sound sequence, such as “sit,” contains individual sounds that occur in many other words in the same position (e.g., initial /σ/, medial /I/, final /τ/) and sound sequences that co-occur in many other words of the language (e.g., /σI/, /Iτ/). In contrast, a rare, sound sequence, such as “these,” contains sounds that infrequently occur in other words in the same position (e.g., initial /Δ/, medial /ι/, final /ζ/) and infrequently co-occur (e.g., /Δι/, /ιζ/).

Phonotactic probability has been shown to influence language processing across the life span. Specifically, adults recognize and produce common sound sequences more rapidly and accurately than rare sound sequences (Levelt & Wheeldon, 1994; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997; Vitevitch & Luce, 1998; 1999). Likewise, adults’ recognition memory is more accurate for common than for rare sound sequences (Frisch, Large, & Pisoni, 2000). Moreover, phonotactic probability affects language processing in children, and this appears early in development. Infants first show sensitivity to the distinction between common versus rare sound sequences at approximately 9-months of age (Jusczyk, Luce, & Charles-Luce, 1994). Infants also are able to learn the phonotactic probability of an artificial language with only minimal exposure (Aslin, Saffran & Newport, 1998; 1999; Saffran, Aslin, & Newport, 1996). Likewise, 6- and 7-year-old children learn the phonotactic probability of an artificial language with minimal incidental exposure (Saffran, Newport, Tunick, & Barrueco, 1997). This evidence suggests that infants and children readily attune to the phonotactic probability of sound sequences. Of particular interest is the potential for phonotactic probability to influence word learning.

A growing body of evidence suggests that phonotactic probability influences nonword repetition performance by children. For example, 3- to 5-year-old children repeat common sound sequences more accurately than rare sound sequences (Beckman & Edwards, 1999). Similarly, 7- and 8-year-old children recall longer lists of nonwords composed of common than rare sound sequences (Gathercole, Frankish, Pickering, & Peaker, 1999). This influence of phonotactic probability on nonword repetition is relevant to word learning because nonword repetition performance has been shown to correlate with lexical development (Gathercole & Baddeley, 1989; 1990; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Willis, Emslie, & Baddeley, 1992). Given these findings, it is predicted that phonotactic probability will also influence word learning with common sound sequences being acquired more rapidly than rare sound sequences in both comprehension and production.

Storkel and Rogers (2000) provide the first direct evidence that phonotactic probability may influence novel word learning. Children, aged 7, 10, and 13 years, were exposed to nonwords paired with unfamiliar object referents. Half the nonwords were composed of common sound sequences, and half were composed of rare sound sequences. Following 7 exposures to each nonword, children identified the referent of each nonword from a field of choices. As predicted, the two older groups of children identified more referents of common than rare sound sequences, but the youngest group of children showed no consistent effect of phonotactic probability. Phonotactic probability appeared to influence lexical acquisition by the two oldest, but not the youngest, groups of children.

The lack of an effect of phonotactic probability for the youngest group in Storkel and Rogers (2000) is curious given that children of this age have shown sensitivity to phonotactic probability in other tasks (Gathercole et al., 1999; Saffran et al., 1997). It may be that the phonological representations of these youngest children were not adult-like. In fact, differences have been reported between children and adolescents in sensitivity to phonotactic information, suggesting that phonological representations may continue to develop throughout childhood

(Pertz & Bever, 1975). Thus, phonotactic probability may be harnessed to support word learning only later in development when phonological representations are more adult-like. This hypothesis fits with other emerging evidence that children may not always use cues they are sensitive to in support of word learning (cf., Rice, Cleave, & Oetting, 2000). An alternative account is that the effect of phonotactic probability on the youngest group's word learning may have been obscured by task limitations. One possibility is that examination of referent learning may have decreased sensitivity to the effect of phonotactic probability. That is, children were given the nonword and had to identify the correct referent. Perhaps phonotactic probability would show a greater influence on learning in a task that emphasized the phonological properties of the nonwords, such as a task requiring identification or production of the nonword itself. A second potential limitation is that the influence of phonotactic probability was investigated at only one point in time. Children may differentially weight cues over the course of acquisition of a particular word with some cues being influential at the outset and other cues being influential only later.

Building upon the previous research, this study considers the influence of age and task limitations on the effect of phonotactic probability on word learning, thereby evaluating two competing hypotheses regarding the age differences reported by Storkel and Rogers (2000). The two hypotheses to be evaluated are: (1) children with less mature phonological systems may fail to harness phonological cues to support word learning; (2) the influence of phonotactic probability may be task-specific. Relative to the issue of age, preschool children were targeted because their productive phonological systems are still developing. If the reported age differences in the effect of phonotactic probability on word learning are attributable to differences in phonological representations, then preschool children should fail to show a difference between learning common versus rare sound sequences. A finding of this type would replicate the finding of Storkel and Rogers with even younger children. Moreover, this finding would suggest that children might not harness phonological cues to support word learning while the phonological system is developing.

Relative to the issue of task, a more fine-grained method of examining word learning was developed that incorporated multiple measures of word learning. Paralleling Storkel and Rogers (2000), one task involved identification of the referent from a field of choices when presented with the nonword. In addition, a second task involved identification of the nonword from a field of choices when the referent was presented, and a third task required spontaneous production of the nonword when the referent was presented. It was hypothesized that the first task would rely more heavily on the child's underlying representation of the referent; whereas, the latter two tasks would rely more heavily on the child's underlying representation of the form. In this way, differences could be detected in the effect of phonotactic probability on referent versus form learning, and this may provide further insights into how phonotactic probability influences word learning. Word learning also was examined at multiple points in the learning process. Children's learning of the nonwords was tested following 1, 4, and 7 exposures to the stimuli and after a 1-week delay without further exposure. This manipulation allowed for examination of the effect of phonotactic probability on word learning at different points in the acquisition process. These two modifications to the method provided evidence to address the impact of potential task limitations in previous research. Specifically, if the reported age differences in the effect of phonotactic probability on word learning are attributable to task limitations, then in this more sensitive task, preschool children should show a learning advantage for common over rare sound sequences.

The current study further extends previous work by examining the effect of phonotactic probability on incorrect responses. Analysis of errors may provide evidence of how phonotactic probability influences the formation of underlying representations. We assume that children have three types of representations: phonological, lexical, and semantic (e.g., Auer, 1993). Phonological representations correspond to phonemes and sequences of phonemes. Presumably, phonotactic probability is coded in phonological representations. Lexical representations coincide with the phonological form of the word as a whole unit. Semantic representations include information about the referent. In this study, we controlled the novel words so that each child accurately produced the component sounds suggesting that a phonological representation of the sounds existed. In this way, when the novel words were encountered, a child needed to create a semantic representation of the referent, a lexical representation of the whole word form, and an association between the two. We hypothesized that analysis of children's error patterns may provide insights into which type of representation, lexical or semantic, may be most affected by phonotactic probability (cf., Lahey & Edwards, 1999; McGregor, 1997). Two factors were considered: (1) error type; (2) measure of learning. Relative to error type, semantic versus unrelated errors allow evaluation of the quality of underlying representations. Semantic errors are presumably indicative of a holistic semantic representation. Specifically, the child may know the global semantic category, but may not have internalized the details that would differentiate one category member from another. In contrast, unrelated errors may indicate a more impoverished lexical or semantic representation. The child may not have internalized even basic attributes of the nonword and its referent. Relative to measures of learning, these two basic error types can be examined in the three tasks that vary in their emphasis on form versus referent learning. This allows investigation of semantic and lexical representations, as well as the associations between the two. Errors in identification of the referent allow examination of the semantic representation; whereas errors in identification or production of the form allow examination of the lexical representation and the connection between semantic and lexical representations.

Method

Participants

Preschool children were recruited from the local community through posted announcements and newspaper advertisements. Thirty-four typically developing children (M = 4; 6; SD = 10 months; range 3; 2-6; 3) participated. All were monolingual native English speakers and passed a hearing screening prior to participation. All children showed age-appropriate productive phonology on the Goldman-Fristoe Test of Articulation (GFTA, Goldman & Fristoe, 1986) and age-appropriate word learning on the Peabody Picture Vocabulary Test-Revised (PPVT-R, Dunn & Dunn, 1981). Mean performance was at the 70th percentile (SD = 22; range 32nd - 99th percentile) on the GFTA and at the 74th percentile (SD = 20; range 30th-99th percentile) on the PPVT-R. Productive phonology was further evaluated using a story re-telling probe to examine each child's production of the consonants used in the word learning stimuli. The target consonants were elicited in the target word position, initial or final, in two familiar lexical items. For example, production of word initial /k/ was elicited in the items "kiss" and "cup." Children listened to a story incorporating these 30 lexical items and then attempted to re-tell the story. If the child did not spontaneously produce a target lexical item, then production was elicited in delayed imitation. Children were required to correctly produce the target consonants to guard against misarticulation of the stimuli.

Stimuli

Nonwords. Eight consonant-vowel-consonant (CVC) nonwords served as the auditory stimuli to be learned. These are shown in Table 1. Half the nonwords were composed of common sound sequences, and half were composed of rare sound sequences. To afford comparisons across published studies, phonotactic probability was determined using a database and an algorithm reported in numerous studies of infants, children, and adults (e.g., Auer, 1993; Jusczyk et al., 1994; Storkel & Rogers, 2000; Vitevitch et al., 1997; Vitevitch & Luce, 1998; 1999). The database consisted of a 20,000 word on-line dictionary containing ratings of word familiarity by adults (Nusbaum, Pisoni, & Davis, 1984) and word frequency counts (KuCera & Francis, 1967). Only words that had been rated as highly familiar by adults (rating $\geq$ 6 on a 7-point scale) were used in the computations (see Auer, 1993). While this database is based on an adult lexicon, previous studies have shown that it yields measures of phonotactic probability that accord well with those based on a child database (Jusczyk et al., 1994). Common versus rare sound sequences were determined using a phonotactic probability algorithm that dually incorporated positional segment frequency and biphone frequency (e.g., Auer, 1993; Jusczyk et al., 1994; Storkel & Rogers, 2000; Vitevitch et al., 1997; Vitevitch & Luce, 1998; 1999). Positional segment frequency was defined as the likelihood of occurrence of a given sound in a given word position. For each segment in the CVC, the log frequency of the words containing the target segment in the target word position was summed and then divided by the sum of the log frequency of the words containing any other segment in the target word position. The positional segment frequency for each segment was then summed to provide a single measure of positional segment frequency for the nonword. Biphone frequency was defined as the likelihood of co-occurrence of two adjacent sounds. For each biphone, the log frequency of the words containing the target biphone in the target word position was summed and then divided by the sum of the log frequency of the words containing the first segment of the biphone followed by any other segment in the target word position. The biphone frequency for the CV and the VC were then summed to provide a single measure of biphone frequency for the nonword. These two measures were computed for every legal English CVC, word or nonword, and then rank ordered. The CVCs were then divided at the median value with all stimuli above the median classified as common and all stimuli below the median classified as rare. Table 1 displays the positional segment and biphone frequencies for the stimuli.

Insert Table 1 Here

Care was taken to select nonwords that were phonologically dissimilar from one another to avoid confusion among the nonwords during the learning task. To accomplish this, phonemes were rarely repeated across the eight nonwords. An additional requirement was that all nonwords be composed of early-acquired consonants, defined as an age of acquisition of 3 years, 6 months or younger, using a 75% criterion (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). To further guard against misarticulation of the nonwords, production was screened prior to participation by having the children produce the nonwords in direct imitation. These productions were transcribed and scored relative to the intended targets. Children produced the nonwords with 100% accuracy.

Referents. The right-hand columns of Table 1 describe the eight object referents that were paired with the nonwords. These object referents were either created or adapted from children's stories. The objects had no apparent corresponding single word label in the ambient language. In an attempt to equate semantic and conceptual factors, referents were selected in pairs from four semantic categories: toys, horns, candy machines, and pets. Nonwords were arbitrarily assigned to referents with the stipulation that one item from a given semantic pair be assigned a common sound sequence and the other item be assigned a rare sound sequence. Nonword-referent pairings were counterbalanced across participants to further ensure that semantic characteristics would be equivalent across common and rare sound sequences.

Story. A story having three distinct episodes was created. Each episode focused on two main characters performing a routine likely to be familiar to young children. The familiar routine varied across episodes. Scenes from children's picture books (Mayer, 1993) were combined and adapted to incorporate the object referents. The semantically paired referents were shown together in the same picture with each being associated with a different main character yielding four pictures. These four pictures occurred in each episode. Six additional pictures were created that showed the two main characters interacting. These pictures served as introductory and concluding scenes for each episode. The story pictures were 8x11 color drawings, mounted on a solid background, and placed in a storybook.

A narrative was created to complement the visual stimuli. Each episode began with several introductory sentences that established the common routine. Then, the target nonwords were presented in their semantic pairs such that the common and rare sound sequences were presented in the same scene. The nonwords were embedded in a sentence. The sentences for each nonword, common or rare, in a semantic pair were virtually identical. This ensured that the syntactic difficulty was equivalent across the common and rare sound sequences. The number of repetitions of a given nonword varied across episodes. In Episode 1, each nonword was presented one time. In Episodes 2 and 3, each nonword was presented three times. An example of exposure sentences across episodes is provided in the appendix. Each episode ended with several concluding sentences that were intended to provide a brief delay between exposure and testing.

A female speaker recorded two versions of the story narrative, corresponding to the counterbalanced pairings of nonwords and referents. The duration of the nonwords in the story was measured to examine potential differences between common versus rare sound sequences. Using a spectrogram, duration was measured from the onset of the initial consonant to the offset of the final consonant. Two judges measured each nonword, and their measurements were averaged. A third judge measured 14% of the nonwords to determine inter-judge reliability. The mean absolute disagreement was 5 ms ($\underline{SD}$ = 7; range 0-29). The mean duration for common sound sequences was 456 ms (SD = 83; range 323-691) and for rare sound sequences was 473 ms (SD = 93; range 301-703). The duration of common and rare sound sequences did not differ significantly ($F(1,18) < 1$; $p > 0.10$). The audio recordings were presented at a comfortable listening level using tabletop speakers.

Measures of Learning

Nonword learning was assessed at four test points which occurred following1 cumulative exposure (Episode 1), 4 cumulative exposures (Episode 2), 7 cumulative exposures (Episode 3), and 1-week post exposure (M = 7 days; SD = 1; range of 3-9 days). At each test point, three measures of learning were obtained: referent identification, form identification, and picture naming.

Referent identification. The referent identification task was a three alternative forced-choice test. In this test, the child heard a pre-recorded target nonword and selected the corresponding referent from a field of three pictures. The three picture alternatives included the target referent, the semantically related referent, and an unrelated referent presented in the story. Responses were scored as correct, semantic error, or unrelated error accordingly. All children passed a pre-training task using this procedure with familiar real words.

Form identification. The form identification task was also a three alternative forced-choice test. The child saw a picture of one of the object referents and selected the corresponding nonword from a field of three pre-recorded auditory nonwords. Each auditory alternative was sequentially presented and paired with a yellow square. Following presentation of all three nonword alternatives, the child pointed to the square indicating his or her response. The three alternatives and scoring procedure paralleled that of the referent identification task. Thirty-two of the 34 children passed a pre-training task using this procedure with familiar real words. Only data from these 32 children was used in the form identification analyses.

Picture naming. In the picture naming task, a picture of one of the object referents was presented and the child attempted to name the object. Responses were phonetically transcribed and later scored. Given the difficulty of this task, a lenient scoring criterion was used. A response was scored as correct if it contained two correct phonemes in the correct word position (see also Dollaghan, 1985). A response was scored as a semantic error if it contained two of the three phonemes of a semantically related nonword. Likewise, a response was scored as an unrelated error if it contained two of the three phonemes of an unrelated nonword presented in the story. For unrelated errors, the phonotactic probability of the unrelated nonword was noted. Real word or novel nonword responses were scored as other errors and were not further analyzed.

Results

Accuracy Analysis

The accuracy analysis was performed for each of the three measures of word learning: referent identification, form identification, and picture naming. In each analysis, the dependent variable was the proportion of correct responses collapsed across individual nonwords. These proportions were submitted to a 2 Phonotactic Probability (common vs. rare) x 4 Exposure (1 vs. 4 vs. 7 vs. 1-week post) repeated measures analysis of variance with Huynh-Feldt correction for sphericity (Huynh-Feldt, 1976). In this analysis, a significant effect would indicate that the effect of the independent variable was consistent across children differing in age, vocabulary knowledge, and articulation ability. Two effect sizes were computed for each independent variable: f^2 and the proportion of the variance accounted for by a given variable (PV). Guidelines given by Cohen (1988) were used to interpret these effect sizes as small, medium, or large. Significant main effects and interactions were followed by planned contrasts using Bonferroni correction. In the case of a significant main effect of Exposure, adjacent test points were compared: 1 versus 4; 4 versus 7; 7 versus 1-week post (p-critical = 0.017). A significant interaction was investigated by comparing common versus rare nonwords at each exposure (p-critical = 0.0125).

Referent identification. Analysis of accuracy in the referent identification task showed a main effect of Phonotactic Probability, F (1, 33) = 8.35, $p < 0.01$, and a main effect of Exposure, F (3, 99) = 8.65, $p < 0.001$. The interaction of Phonotactic Probability x Exposure was not significant, $F < 1$, $p > 0.10$. Figure 1 shows the proportion correct for common versus rare sound sequences following 1, 4, and 7 cumulative exposures as well as 1-week post exposure. Points falling between the solid black lines indicate performance not significantly different from chance (0.33). From this figure, several observations can be made. One observation is that across children differing in age and vocabulary knowledge, the referents of common sound sequences were consistently identified more accurately than those of rare sound sequences. Identification of the referents of common sound sequences was above chance following 1 exposure and remained above chance at all subsequent test points. In contrast, referent identification of rare sound sequences was not above chance until 4 exposures, but also remained above chance at all subsequent test points. The phonotactic probability of the nonword accounted for 20% of the variance in referent identification performance (f^2 = 0.25, medium effect). A second observation is that performance for both common and rare sound sequences improved over exposures. Referents were identified more accurately following 7 exposures than following 4 exposures, F (1,99) = 6.59, $p < 0.01$. No other comparisons of adjacent test points were significant. The number of exposures accounted for 21% of the variance in performance (f^2 = 0.26, medium effect).

Insert Figure 1 Here

Form identification. For the form identification task, there was a main effect of Phonotactic Probability, F (1,31) = 12.64, $p < 0.001$, and a main effect of Exposure, F (3, 93) = 3.06, $p < 0.05$. The interaction of Phonotactic Probability x Exposure failed to reach significance, $F < 1$, $p > 0.10$. Figure 2 shows the proportion of correct responses in the form identification task as well as chance performance. The common sound sequences were identified more accurately than the rare, and this difference was maintained at each exposure. Responses to common sound sequences were above chance at all exposure points; whereas responses to rare sound sequences were not above chance until 1-week post exposure. Phonotactic probability accounted for 29% of the variance in form identification ($f^2 = 0.41$, large effect). In addition, performance had a tendency to increase across exposures. The difference between 1-week post exposure and 7 exposures approached significance, F (1, 93) = 5.27, $p < 0.05$. No other comparisons of adjacent exposure points approached or reached significance. The number of exposures accounted for 9% of the variance in performance ($f^2 = 0.10$, small effect).

Insert Figure 2 Here

Picture naming. Analysis of variance showed a main effect of Phonotactic Probability, F (1,33) = 10.23, $p < 0.01$, a main effect of Exposure, F (3, 99) = 16.82, $p < 0.001$, and a significant interaction of Phonotactic Probability x Exposure, F (3,99) = 8.19, $p < 0.001$. Figure 3 shows the proportion of correct responses in the picture naming task. In terms of the effect of phonotactic probability, common sound sequences were named more accurately than rare. Phonotactic probability accounted for 24% of the variance in naming performance ($f^2 = 0.31$, medium effect). Naming tended to increase in accuracy over exposures. The difference between naming performance following 1 versus 4 exposures approached significance, F (1, 99) = 6.02, $p < 0.02$. Additionally, naming 1-week post exposure was significantly more accurate than following 7 exposures, F (1,99) = 11.53, $p < 0.01$. The number of exposures accounted for 31% of the variance in performance ($f^2 = 0.46$, large effect). The significant interaction of Phonotactic Probability x Exposure appeared to be attributable to a lesser or greater discrepancy between common versus rare sound sequences at particular exposures. Specifically, the advantage of common over rare sound sequences was particularly reduced following 1 exposure. This reduction is likely attributable to a floor effect, where performance was near 0% accuracy. A floor effect would obscure any difference between common versus rare sound sequences. In contrast, the difference between common versus rare sound sequences was particularly large at 1-week post exposure, F (1,99) = 47.57, $p < 0.001$, and approached significance following 4 exposures, F (1,99) = 3.73, $p < 0.10$. This interaction accounted for 17% of the variance ($f^2 = 0.21$, medium effect).

Insert Figure 3 Here

Correlation analysis. Results of the ANOVAs showed that preschool children varying in age, vocabulary knowledge, and articulation ability consistently acquired common sound sequences more rapidly than rare. While children showed a consistent advantage of common over rare sound sequences, it is possible that the magnitude of this difference might increase or decrease with age, vocabulary development, or phonological acquisition. To explore this possibility, difference scores between common and rare sound sequences were computed for each child in each task and were submitted to a correlational analysis with measures on standardized tests and age. Raw score on the PPVT was significantly correlated with difference scores on the referent identification task (r (34) = 0.36; $p < 0.05$). As receptive vocabulary increased, the advantage of common over rare sound sequences in referent learning also increased. Errors on the GFTA and chronological age were not significantly correlated with difference scores on the referent identification task (r (34) = -0.26, $p > 0.10$ and r (34) = 0.30, $p >$

0.05 respectively). A different pattern was observed in the two measures that emphasized learning of the phonological form. Difference scores on the form identification tasks were not significantly correlated with PPVT raw score (r (32) = 0.12, $p > 0.50$), GFTA errors (r (32) = -0.05, $p > 0.50$), or chronological age (r (32) = 0.07, $p > 0.50$). Likewise, difference scores on the picture naming task were not significantly correlated with PPVT raw score (r (34) = -0.04, $p > 0.50$), GFTA errors (r (34) = -0.09, $p > 0.50$), or chronological age (r (34) = 0.25, $p > 0.10$).

Semantic Error Analysis

The goal of the semantic error analysis was to examine the influence of phonotactic probability on the formation of holistic representations. In the semantic error analysis, the dependent variable was the number of semantic errors divided by the total number of errors excluding no response trials. This proportion was computed for each participant collapsed across individual nonwords and was submitted to a 2 Phonotactic Probability (common vs. rare) x 4 Exposure (1 vs. 4 vs. 7 vs. 1-week post) repeated measures analysis of variance with Huynh-Feldt correction for sphericity (Huynh-Feldt, 1976). Significant main effects and interactions were followed-up using the same methods described in the Accuracy Analysis.

Referent identification. There was a main effect of Phonotactic Probability, F (1, 33) = 6.75, $p < 0.01$. The main effect of Exposure and the interaction of Phonotactic Probability x Exposure failed to reach significance, $F < 1$, $p > 0.10$. The top panel of Figure 4 shows the proportion of semantic errors for common versus rare sound sequences following 1, 4, and 7 cumulative exposures as well as 1-week post exposure. In terms of the effect of phonotactic probability, there were more semantic errors for common than rare sound sequences. Children were more likely to know the category of the referent of common, rather than rare, sound sequences. This suggests that the referents of common sound sequences were more likely to have a holistic semantic representation than those of rare sound sequences.

Insert Figure 4 Here

Form identification. There was a main effect of Phonotactic Probability, F (1, 31) = 6.14, $p < 0.05$, and a main effect of Exposure, F (3, 93) = 2.72, $p < 0.05$. The interaction of Phonotactic Probability x Exposure failed to reach significance, $F < 1$, $p > 0.10$. The top panel of Figure 5 shows the proportion of semantic errors for common versus rare sound sequences following 1, 4, and 7 cumulative exposures as well as 1-week post exposure. In contrast to the referent identification task, there were more semantic errors for rare than common sound sequences. When given the referent of a rare sound sequence, children tended to select the semantically-related common sound sequence. This suggests that children were more likely to associate a holistic semantic representation with the lexical representation of the common sound sequences than with the lexical representation of the rare sound sequence. In terms of the main effect of exposure, none of the pairwise comparisons of adjacent test points reached significance, but the trend was for an increase in semantic errors over exposures. This indicates that learning of associations between referents and forms was more likely with increasing exposure.

Insert Figure 5 Here

Picture naming. The main effect of Phonotactic Probability approached significance, F (1,33) = 3.08; $p < 0.10$, and the main effect of Exposure was significant, F (3, 99) = 7.44, $p < 0.01$. These main effects were qualified by a significant interaction of Phonotactic Probability x Exposure, F (3, 99) = 3.56, $p < 0.05$. Figure 6 shows the proportion of semantic errors for common versus rare sound sequences following 1, 4, and 7 cumulative exposures as well as 1-week post exposure. As in the form identification task, there was a tendency for rare sound sequences to elicit more semantic errors than common and for semantic errors to increase over exposures. The significant interaction is attributable to the finding of significantly more semantic errors for rare than for common sound sequences only at 1-week post exposure, F (1, 99) =

13.16, $p < 0.001$. As in the form identification task, holistic semantic representations were more likely to be associated with common sound sequences than with rare sound sequences 1-week post exposure.

Insert Figure 6 Here

Unrelated Error Analysis

The dependent variable for each measure of learning was the proportion of unrelated errors to the total number of errors. The proportions for the referent and form identification tasks were then submitted to a 2 Phonotactic Probability (common vs. rare) x 4 Exposure (1 vs. 4 vs. 7 vs. 1-week post) repeated measures analysis of variance with Huynh-Feldt correction for sphericity (Huynh-Feldt, 1976). Significant main effects and interactions were followed-up using the same methods described in the Accuracy Analysis. The analysis of the unrelated errors for the picture naming task was more complex. In this analysis, the phonotactic probability of the error was also considered. The resulting analysis was a 2 Target Phonotactic Probability (common vs. rare) x 2 Error Phonotactic Probability (common vs. rare) x 4 Exposure (1 vs. 4 vs. 7 vs. 1-week post) repeated measures ANOVA. This more complex analysis was not used in the referent and form identification tasks because only one unrelated alternative was presented as a possible response choice in these two tasks. Thus, on any given trial, the participant did not have equal opportunity to respond with an unrelated item that was either a common or rare sound sequence. Note that when making comparisons across semantic and unrelated errors, the sum of the mean proportions does not equal 1.00 because some children did not produce any incorrect responses at certain exposures, and the averaging of these values leads to an intermediate sum between 0.00 and 1.00.

Referent identification. There was a main effect of Phonotactic Probability, $F(1, 33) = 9.64$; $p < 0.01$. The main effect of Exposure and the interaction of Phonotactic Probability x

Exposures failed to reach significance, $F < 1$, $p > 0.10$. The bottom panel of Figure 4 shows the proportion of semantic errors for common versus rare sound sequences across cumulative exposures. There were more unrelated errors for rare than common sound sequences, meaning that children selected unrelated objects as the referents for rare sound sequences more often than for common sound sequences. This finding suggests that children were less likely to recall even partial information about the referents of rare sound sequences. Thus, semantic representations of the referents of rare sound sequences tended to be impoverished.

Form identification. The main effect of Phonotactic Probability and the interaction of Phonotactic Probability x Exposure both failed to reach significance, $F < 1$, $p > 0.10$. There was a significant main effect of Exposure, $F(3, 93) = 4.67$, $p < 0.01$. The bottom panel of Figure 5 displays the pattern of unrelated errors for common and rare sound sequences. Children were equally likely to choose an unrelated nonword for rare and common sound sequences. This suggests that rare and common sound sequences were equally likely to have impoverished lexical representations. In terms of the main effect of exposure, the trend was for unrelated errors to decrease over time; although comparisons of adjacent exposure points were not statistically significant. As exposures increased, children increasingly formed associations between referents and forms.

Picture naming. There was a main effect of Error Phonotactic Probability, $F(1, 33) = 6.12$, $p < 0.05$, and of Exposure, $F(3, 99) = 3.61$, $p < 0.05$. The other main effects and interactions failed to reach significance, $F < 1.5$, $p > 0.10$. As in the form identification task, children's unrelated errors were unaffected by the phonotactic probability of the target nonword. In contrast, children's unrelated errors were influenced by the phonotactic probability of the substituted nonword. The top panel of Figure 7 shows the pattern of unrelated errors when the targets were common sound sequences; whereas the bottom panel of Figure 7 shows the pattern when the targets were rare sound sequences. When children responded with an unrelated nonword, the substituted nonword tended to be composed of rare rather than common sound sequences regardless of the phonotactic probability of the target. Children seemed to have some knowledge of the rare sound sequences but tended not to produce these nonwords target appropriately. This suggests that children had a detailed lexical representation of rare sound sequences but were unlikely to associate these with a semantic representation. Presumably, association with a detailed or holistic semantic representation would block the child from providing the nonword as a response to an unrelated item (e.g., mutual exclusivity constraint). In terms of the effect of Exposure, there was a tendency for unrelated errors to increase over time; however, none of the planned contrasts involving adjacent exposure points reached significance. In general, production of both common and rare sound sequences tended to increase with greater exposure.

Insert Figure 7 Here

Discussion

The effect of phonotactic probability on word learning by young children was investigated using a word learning task that incorporated multiple measures of learning, sampled learning following multiple numbers of exposures, and examined both correct and incorrect responses. It was intended that the results would provide insights into the null effect of phonotactic probability on word learning by 7-year-old children in previous work (Storkel & Rogers, 2000). Moreover, it was hypothesized that error analyses might offer insights into word learning mechanisms by providing evidence of the aspect of word learning that is affected by phonotactic probability. These issues then bear upon theories of word learning, potentially differentiating associationistic from constraint theories.

Comparison to Past Work

The findings indicated that preschool children more rapidly acquired common than rare sound sequences. This parallels the effect observed in the two oldest groups, but not the youngest group, of Storkel and Rogers (2000). Importantly, the current findings suggest that the lack of an effect of phonotactic probability on word learning by the youngest group in this previous work may not be attributable to changes in the ability to use phonological representations to support word learning. It seems that even young children who are still developing productive phonology are able to capitalize on the phonological regularities of the language to promote acquisition. This finding suggests that a language subsystem need not be adult-like to play a role in lexical acquisition. That is not to say that further development in an area of language would not have consequences for word learning. In fact, the advantage of common over rare sound sequences in referent learning increased as children's receptive vocabulary increased. Of course with correlation analyses, the direction of causation can not be inferred. That is, acquisition of words may reinforce the phonotactics of the language, leading to greater reliance on phonological regularities to support word learning. Alternatively, the development of greater reliance on phonological cues may lead to more efficient word learning and thereby increase the child's receptive vocabulary. In either case, an increased common sound sequence advantage in referent learning and expansion of the lexicon appeared to go hand-in-hand. Interestingly, a similar relationship between language development and measures related to form learning was not observed. This may, in part, be attributable to the fact that standardized measures of expressive vocabulary development were not available as predictors.

Since no support was found for the hypothesis that developmental differences in phonology may explain the previously reported null result, the influence of task was considered in terms of consistency in the effect of phonotactic probability across measures of word learning and across exposures. The advantage of common over rare sound sequences was observed in all three measures of learning. Although phonotactic probability accounted for a larger proportion of variance in form than referent learning, phonotactic probability did significantly influence acquisition of the referent, the form, and the production of the nonwords. Therefore, the lack of an effect of phonotactic probability in the earlier study does not seem to stem from the use of measures tapping referent learning rather than form learning. Furthermore, the advantage of common over rare sound sequences was consistent across exposures during learning and across a 1-week delay. This was true in the referent identification and form identification tasks. The picture naming task showed inconsistencies in the effect of phonotactic probability across exposures, but this was primarily due to a floor effect following 1 exposure. In addition, a reversal of the common sound sequence advantage was never observed. Taken together, it did not seem that children differentially weighted cues over the course of acquisition of a particular word.

The null effect of phonotactic probability for the youngest group in Storkel and Rogers (2000) remains puzzling in light of these new findings. Explanations related to developmental differences in phonology and task limitations were not supported; however, these factors still may have played a role. The current study tightly controlled the relationship between children's productive phonology and the phonological composition of the stimuli to be learned. Specifically, children were required to accurately produce the target sounds in both real words and target nonwords. This was not the case in Storkel and Rogers. Thus, it may be that the youngest group misarticulated the nonwords and this influenced learning more than phonotactic probability. An alternative possibility is that the null result for the youngest group was attributable to floor effects. While the mean for the youngest group was above chance, individual children did perform at chance level. The poor performance of these children may have obscured the presence of an effect of phonotactic probability in the children who performed above chance.

Word Learning Mechanisms

Error analyses provided evidence of how phonotactic probability influenced the creation of underlying representations. First, phonotactic probability seemed to play a role in the formation of a semantic representation of the referent. Referents of common sound sequences were likely to have a holistic semantic representation, giving rise to semantic errors in the referent identification task. In contrast, referents of rare sound sequences were likely to have an impoverished semantic representation leading to unrelated errors in the referent identification task. Second, phonotactic probability appeared to influence the development of an underlying association between semantic and lexical representations. Specifically, holistic semantic representations were more likely to be associated with a common, rather than a rare, sound sequence. This is supported by the greater number of semantic errors for rare sound sequences in the form identification and picture naming tasks. Furthermore, rare sound sequences were more likely than common sound sequences to be produced as the name of unrelated referents in the picture naming task. This indicates that children may have an underlying lexical representation of the rare sound sequences, as well as the articulatory capability to produce them, but may not have associated these sequences with a semantic representation. Thus, common sound sequences were more likely than rare to have an association between lexical and semantic representations potentially accounting for their advantage. Finally, it was not possible to fully evaluate the effect of phonotactic probability on the formation of a lexical representation because children did not have the opportunity to make lexical errors in the form identification and picture naming tasks. That is, the stimuli were created to be phonologically dissimilar from one another, and foils were only drawn from this stimulus set. Given that form based errors were not possible, it is difficult to evaluate and compare the quality of lexical representations of common versus rare sound sequences. This serves as an important point for future investigations, but it appears that phonotactic probability affects the formation of both a semantic representation and an association between semantic and lexical representations.

The effect of exposure provided further insights into word learning mechanisms. In particular, accurate responses tended to increase after a 1-week delay with no exposure. This increase in response accuracy following a delay has been observed in other word learning studies (e.g., Rice, Oetting, Marquis, Bode, & Pae, 1994). There are several possible explanations for this finding. One possibility is that some type of memory consolidation occurred post exposure. These newly learned nonwords may be more fully integrated into the lexicon by making connections with other similar sounding words. Connections to existing words in the lexicon may further reinforce underlying representations and may account for improvements in performance at post-testing. An alternative possibility is that children may have continued to practice the nonwords. Although it is unlikely that the exact referent or form would be encountered, children may have attempted to generalize the nonwords to novel exemplars, and this may have further reinforced their learning. A final possibility is that children were released from fatigue effects at the 1-week post exposure test. This hypothesis assumes two opposing forces during the immediate learning phase: exposure and fatigue. Increasing exposures presumably supports creation of an underlying representation improving performance, but in-parallel increased time-on-task creates fatigue reducing performance. As a result, following 7 exposures, the child may have the most detailed underlying representation but may be the most fatigued. At the 1-week post exposure test, the child may still have a detailed underlying representation but is not fatigued; so optimal performance is obtained.

Theories of Word Learning

These insights into the influence of phonotactic probability on word learning may be accounted for by either associationistic or constraint theories. Associationistic theories assume that experience with the language attunes the child's attention to regularities in the language. This theory predicts that children should learn phonotactic probability and should use this information to support word learning, as was observed. As the child gains further experience with the language, attentional tuning to regularities should become stronger, accounting for the observation that the common sound sequence advantage increased as vocabulary increased. In addition, the associationistic theory can be integrated with a limited capacity account of language processing to provide one explanation of the global effect of phonotactic probability on multiple aspects of word learning. In this account, it is assumed that a limited pool of resources is available (Baddeley, 1986, 1996; Bloom, 1993; Gathercole & Baddeley, 1993; Just & Carpenter, 1992). If the demand for resources exceeds the limited pool available, then language processing and storage may be degraded. When a new word is encountered, it presumably activates phonological, lexical, and semantic representations. Novel words associated with novel objects will not match an existing lexical or semantic representation, but will likely match existing phonological representations. For this reason, phonological processing may be highly influential in establishing these new lexical and semantic representations. If the novel word is composed of common sound sequences, then phonological processing is predicted to be facilitated. This facilitation of phonological processing may allow greater allocation of resources to lexical and semantic processing. In this scenario, it is less likely that the demand for resources will exceed the limited pool. As a result, creation of new lexical and semantic representations, as well as connections between representations, is more likely to be successful. In contrast, if the novel word is composed of rare sound sequences, then phonological processing may require greater resources. Given this, the demand for resources may potentially exceed the limited pool available. Consequently, lexical and semantic processing may be more likely to fail. This claim related to segmental effects on word learning is consistent with accounts of suprasegmental effects on word learning. In particular, manipulation of rate and emphatic stress has been shown to influence word learning performance (e.g., Ellis Weismer & Hesketh, 1996; 1998). Here, in challenging listening conditions, such as a fast speaking rate during exposure, it is proposed that the formation of underlying lexical and semantic representations are more likely to fail because more resources are devoted to phonological processing than in less challenging listening conditions (e.g., Ellis Weismer & Hesketh, 1996). The associationistic account of word learning predicts the common sound sequence advantage, and the limited capacity account of language processing provides a means of understanding the impact of phonotactic probability on the formation of multiple types of representation.

An alternative account is one based on constraint theories. Here, children might develop a constraint that common sound sequences are likely to be words in the language. As a result, children might have a bias to attend to common sound sequences and to associate them with novel object referents. In complement, children may be more likely to ignore rare sound sequences and thus less likely to accept a rare sound sequences as the name of a novel object. Rare sound sequences might be acquired more slowly because the child would need more encounters with the word-object pairing to override the common sound sequence constraint. This proposed constraint differs from several previously established constraints in that it could not be formed without exposure to the ambient language. That is, the child would need some experience with the language to learn which sound sequences are common and which are rare, making this a less preferred constraint. Golinkoff et al. (1994), however, recently proposed an integrated constraint framework that assumes that the basic constraints necessary to begin learning words are initially present, but that these constraints are affected by experience with the ambient language, giving rise to a second set of constraints. This framework may be able to account for the observed common sound sequence advantage. In particular, a child might initially have a more general constraint to associate the label most frequently heard paired with an object as the name of the object, and this might later develop into a constraint related to regularities in the language.

Both the associationistic and constraint theories may account for the common sound sequence advantage in word learning. Associationistic theories may also account for other instances of a common sound sequence advantage (e.g., Beckman & Edwards, 1999; Gathercole et al., 1999). If it is assumed that language processing is always constrained by a limited capacity, then speeded processing should lead to improved performance across tasks. That is, memory should be enhanced for those items which facilitate phonological processing, namely common sound sequences (e.g., Gathercole et al., 1999). Thus, it may not be necessary to propose specific constraints to account for patterns in lexical acquisition (see also Plunkett, 1997; Smith, 1995; 1999). Associationistic theories may be preferable because they offer a more parsimonious account of the common sound sequence advantage across tasks and across ages.

It is important to note that this common sound sequence advantage in word learning was demonstrated in an experiment where phonological, semantic, syntactic, and environmental variables were controlled as much as possible. Given this level of control, it is unclear to what extent phonotactic probability would influence word learning in a more naturalistic setting. Lexical acquisition in less controlled contexts is likely to be influenced by multiple stimulus factors. It is possible that phonotactic probability would have a more minimal impact on word learning in a naturalistic setting or might even be overshadowed by the stronger influence of other variables. This possibility does not necessarily discount the importance of the current findings because these results from a controlled laboratory study may reveal the status of underlying word learning mechanisms that may not be readily apparent, but may still be influential, in naturalistic settings.

Conclusion

This study served as an important extension of previous work providing support for several insights about word learning. First, children who were still developing productive phonology were able to use phonological cues to support word learning. This suggests that a language subsystem need not be fully developed to influence lexical acquisition. Second, phonological regularities appeared to influence the formation of multiple types of representations including semantic representations and associations between lexical and semantic representations. Thus, the effect of phonology on word learning was global rather than circumscribed. Finally, these findings lend support to associationistic theories that hypothesize that children are able to learn multiple regularities of the language, and that these regularities may be harnessed to support the rapid acquisition of novel words. The global effect of phonotactic probability on word learning appeared consistent with limited capacity accounts of language processing. These two hypotheses provided an integration of theories of word learning with theories of language processing.

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Appendix: Sample Exposure for the Toy Referents

	Common Sound Sequence	Rare Sound Sequence
Episode 1	“We can go to the candy machines at the park,” said Big Brother.	Little Sister said,
(1 exposure)	“My favorite is the /πιν/.”	“My favorite is the /μ□Iδ/.”
Episode 2	“I can eat more candy than you,” said Big Brother.	
(3 exposures)	Big Brother ran to the /πιν/. He got candy from the /πιν/. He stuffed all the candy from the /πιν/ in his mouth.	Little Sister ran to the /μ□Iδ/. She got candy from the /μ□Iδ/. She stuffed all the candy from the /μ□Iδ/ in her mouth.
	“Can you eat that much?”	Then, they got more candy for later.
Episode 3	“Let’s eat our leftover candy before mom and dad come home,” said Little Sister.	
(3 exposures)	Big Brother got his candy from the /πιν/. He ate all his candy from the /πιν/. “Mmm,” he said, “the candy from the /πιν/ is really good.”	Little Sister got her candy from the /μ□Iδ/. She ate all her candy from the /μ□Iδ/. “Mmm,” she said, “the candy from the /μ□Iδ/ is really good.”

Note. Exposure sentence(s) for common sound sequences were followed by those for rare for this semantic pair. Order of exposure sentences for common versus rare sound sequences was counterbalanced across semantic pairs.

Table 1

Form and Referent Characteristics of the Stimuli

Common Sound Sequence	Positional Segment Frequency	Biphone Frequency	Rare Sound Sequence	Positional Segment Frequency	Biphone Frequency	Category	Referent 1	Referent 2
ωΘτ	0.1657	0.0066	ναΥβ	0.0595	0.0004	Toy	punch toy (Geisel & Geisel, 1958; p. 53)	cork gun (Geisel & Geisel, 1958; p. 45)
η℘π	0.1157	0.0036	γιμ	0.1072	0.0013	Horn	orange trumpet bell pointing down (Geisel & Geisel, 1954; p. 50)	yellow hand-held tuba (Geisel & Geisel, 1954; p. 50)
πιν	0.2123	0.0053	μ□Ιδ	0.0986	0.0004	Candy Machine	red candy + 1 shoot (invented)	blue candy + 2 shoots (invented)
κοΥφ	0.1617	0.0066	φεΙπ	0.0742	0.0018	Pet	green gerbil+antenna (DeBrunhoff, 1981; p. 132)	purple mouse-bat (Mayer, 1992,p. 43)

Figure Captions

Figure 1. Mean proportion of correct responses in the referent identification task for common (squares) versus rare (circles) sound sequences following 1, 4, 7 and 1-week post exposure. Error bars represent standard error. Note that proportions greater than 0.35 or less than 0.30 differ significantly from chance (exact binomial, $p < 0.05$).

Figure 2. Mean proportion of correct responses in the form identification task for common (squares) versus rare (circles) sound sequences following 1, 4, 7 and 1-week post exposure. Error bars represent standard error. Note that proportions greater than 0.36 or less than 0.30 differ significantly from chance (exact binomial, $p < 0.05$).

Figure 3. Mean proportion of correct responses in the picture naming task for common (squares) versus rare (circles) sound sequences following 1, 4, 7 and 1-week post exposure. Error bars represent standard error.

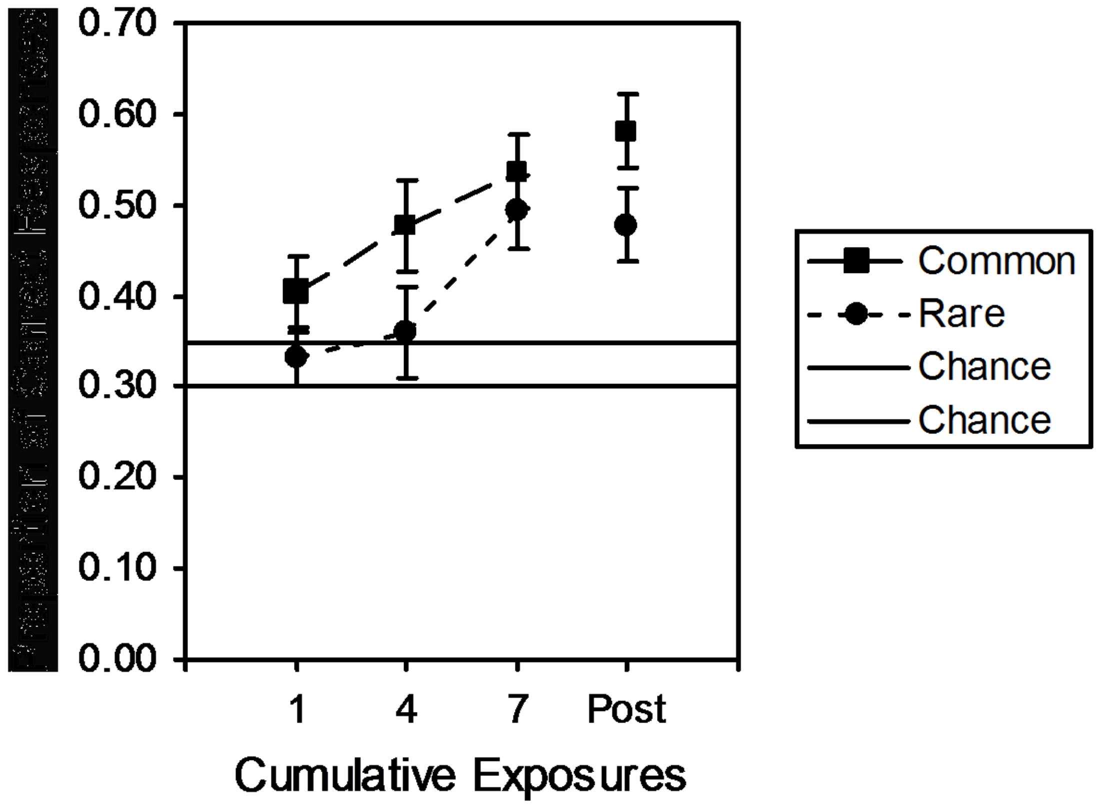
Figure 4. Proportion of semantic errors (top panel) and unrelated errors (bottom panel) in the referent identification task for common (squares) versus rare (circles) sound sequences following 1, 4, 7 and 1-week post exposure. Error bars represent standard error.

Figure 5. Proportion of semantic errors (top panel) and unrelated errors (bottom panel) in the form identification task for common (squares) versus rare (circles) sound sequences following 1, 4, 7 and 1-week post exposure. Error bars represent standard error.

Figure 6. Proportion of semantic errors in the picture naming task for common (squares) versus rare (circles) sound sequences following 1, 4, 7 and 1-week post exposure. Error bars represent standard error.

Figure 7. Proportion of unrelated errors in the picture naming task when the target nonword was a common sound sequence (top panel) versus a rare sound sequence (bottom panel) following 1,

4, 7 and 1-week post exposure. Phonotactic probability of the substitute nonword is indicated by symbol fill: common (filled) versus rare (unfilled). Error bars represent standard error.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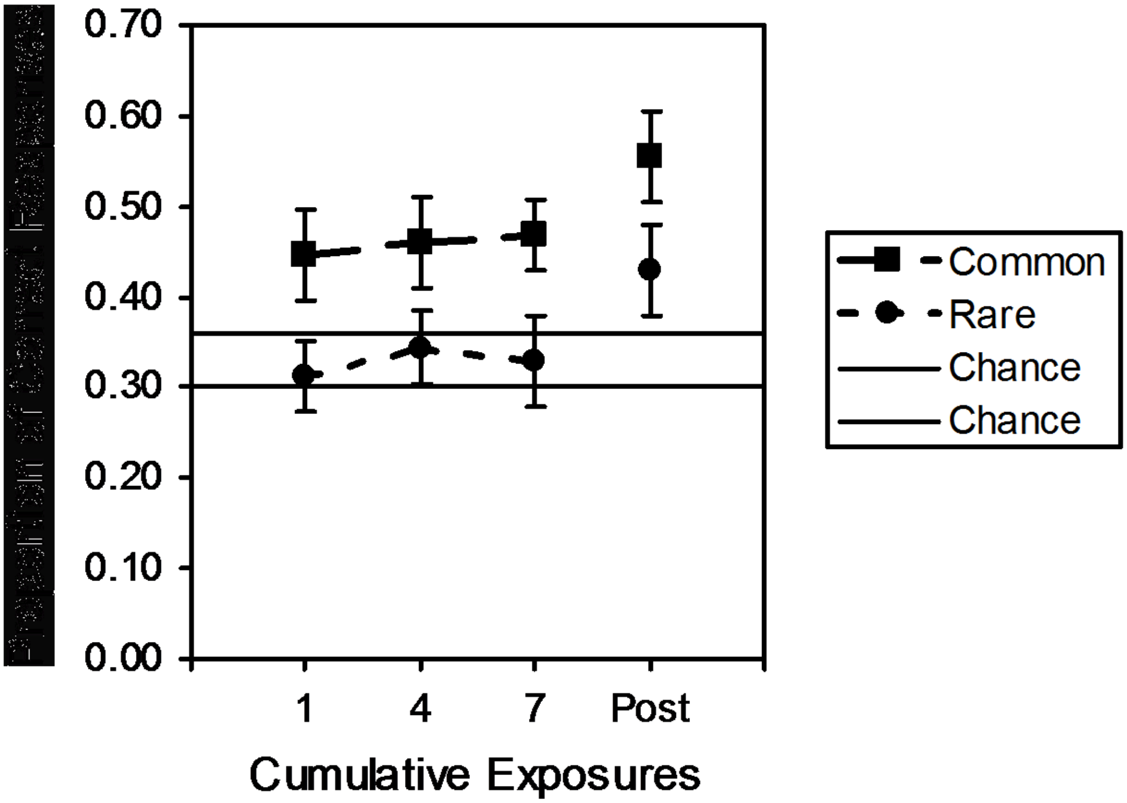
Post
Cumulative Exposures
Common
Rare
Chance
Chance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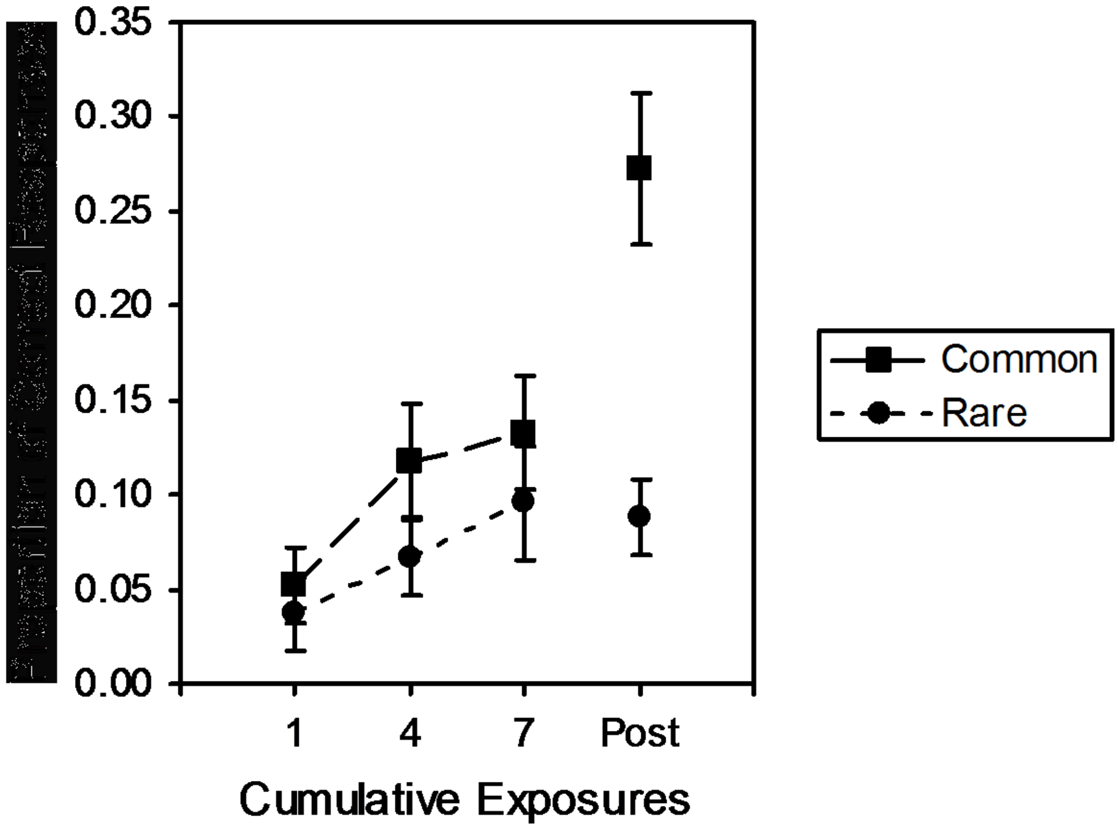
Chance
Chance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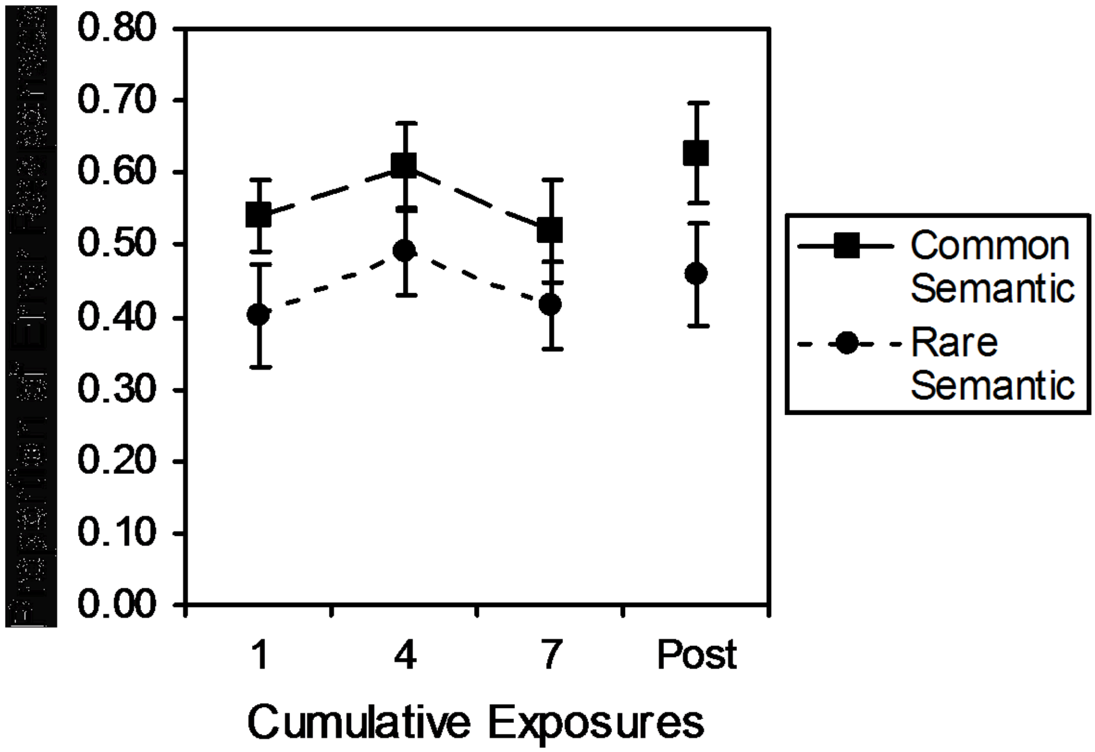
Common
Rare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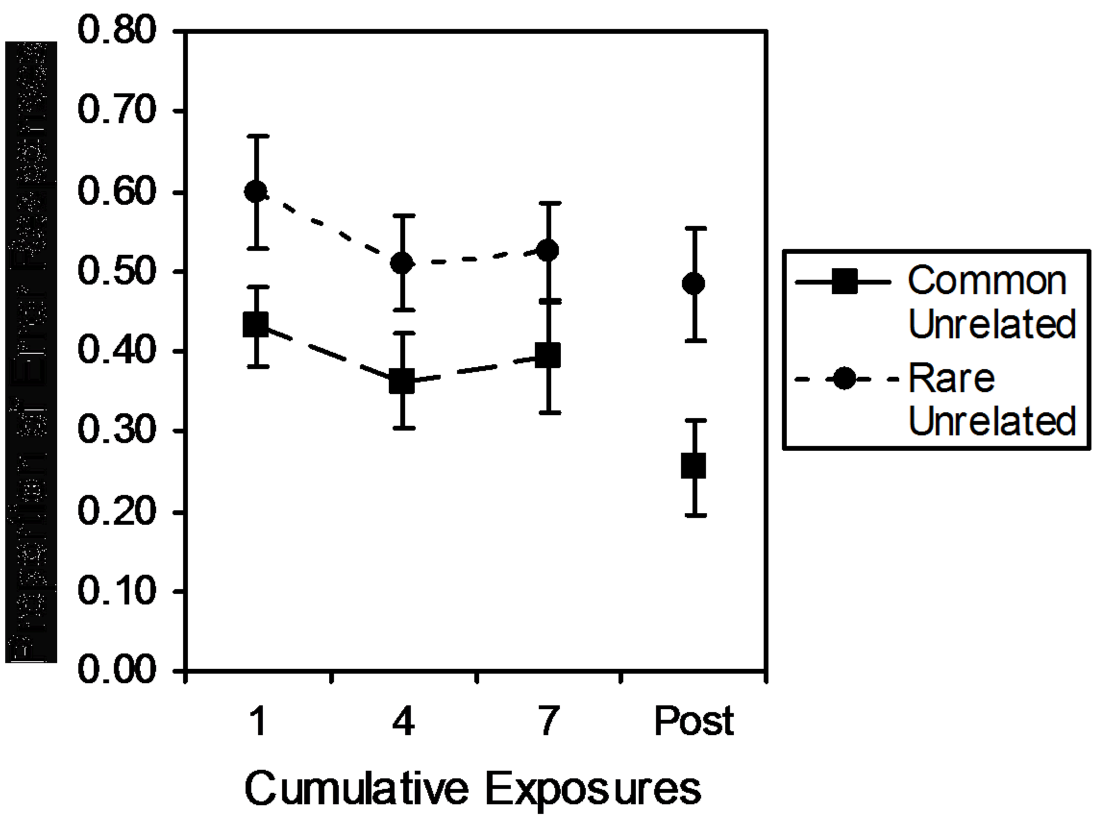
Common Semantic
Rare Semantic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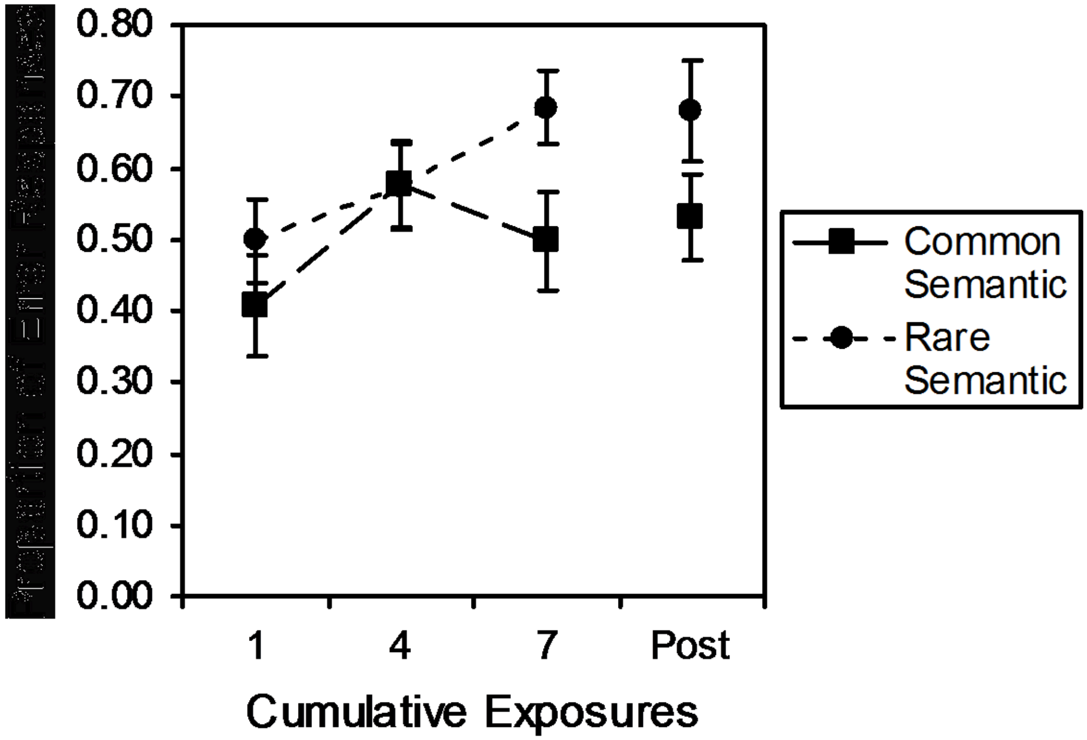
Common Unrelated
Rare Unrelated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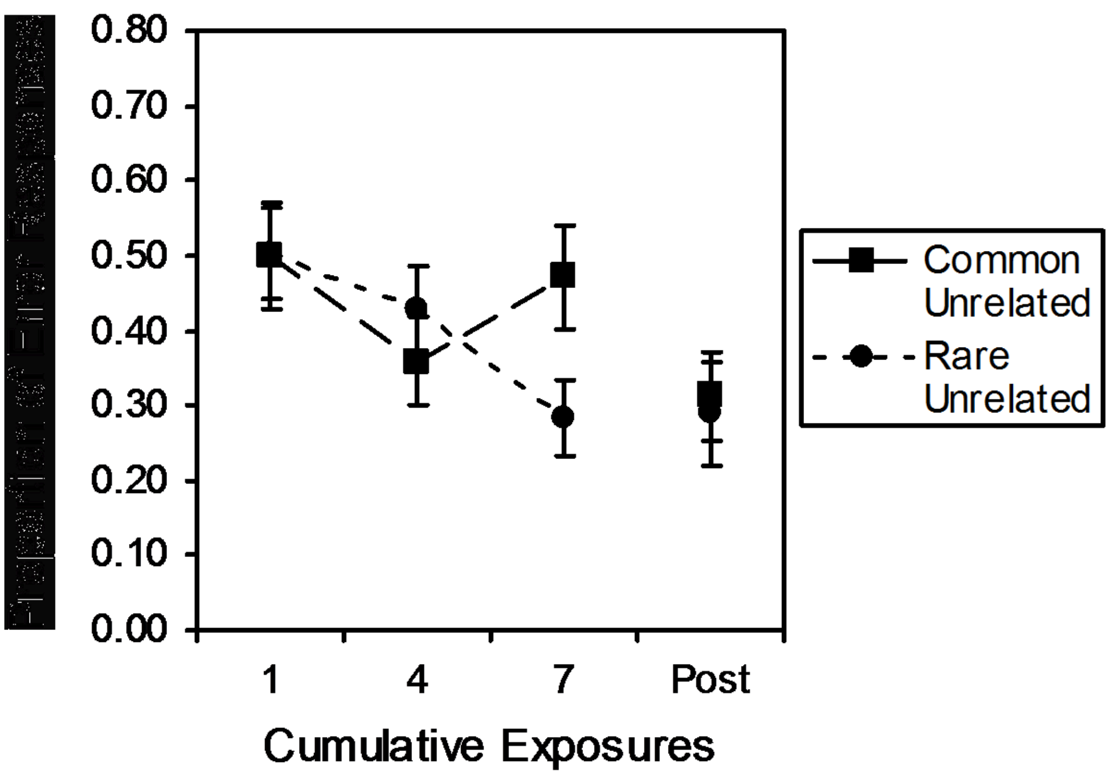
Common Semantic
Rare Semantic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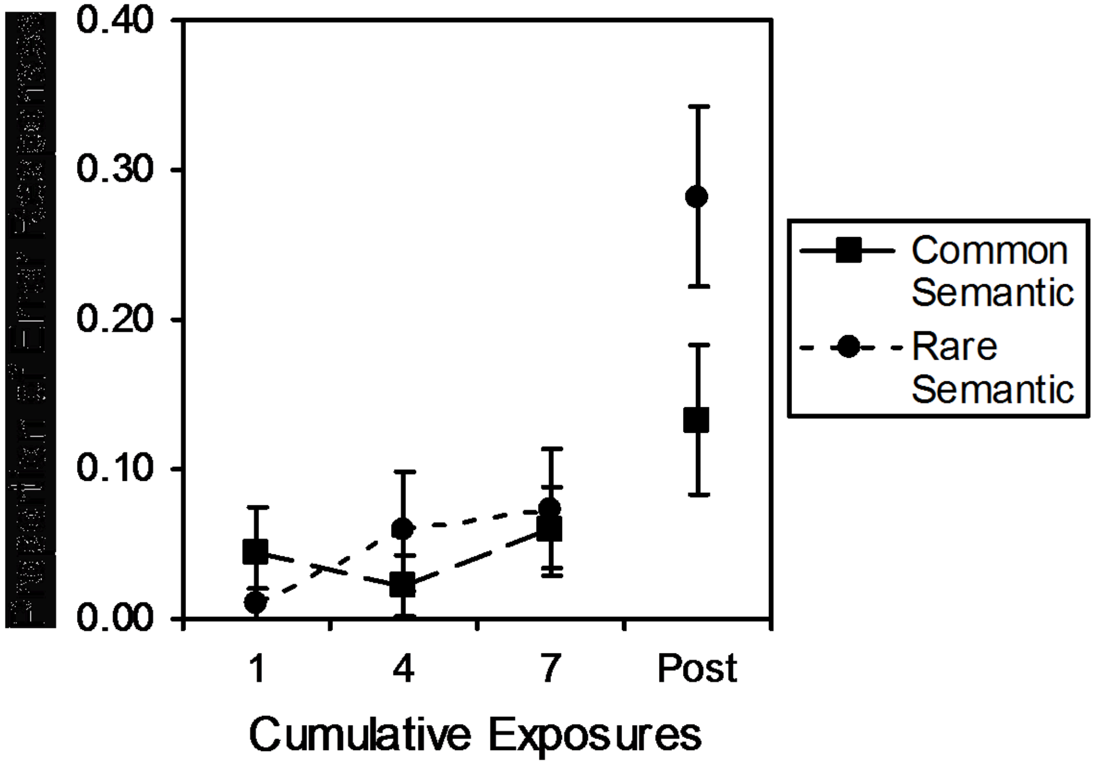
Common Unrelated
Rare Unrelated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4
7
Post
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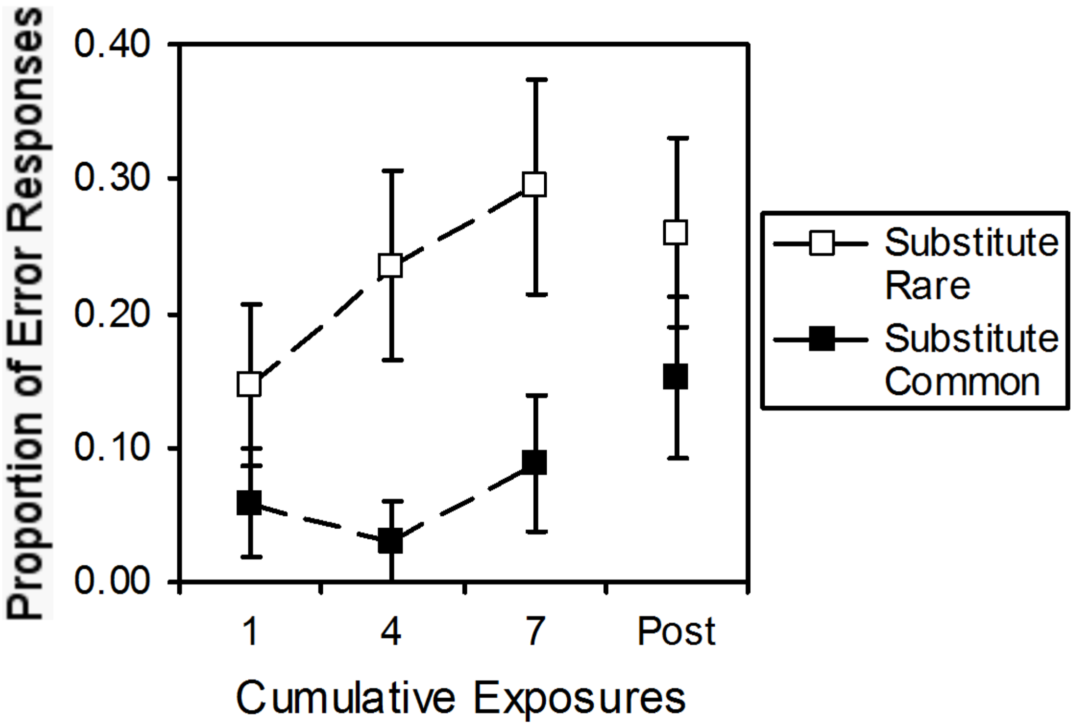
Common Semantic
Rare Semantic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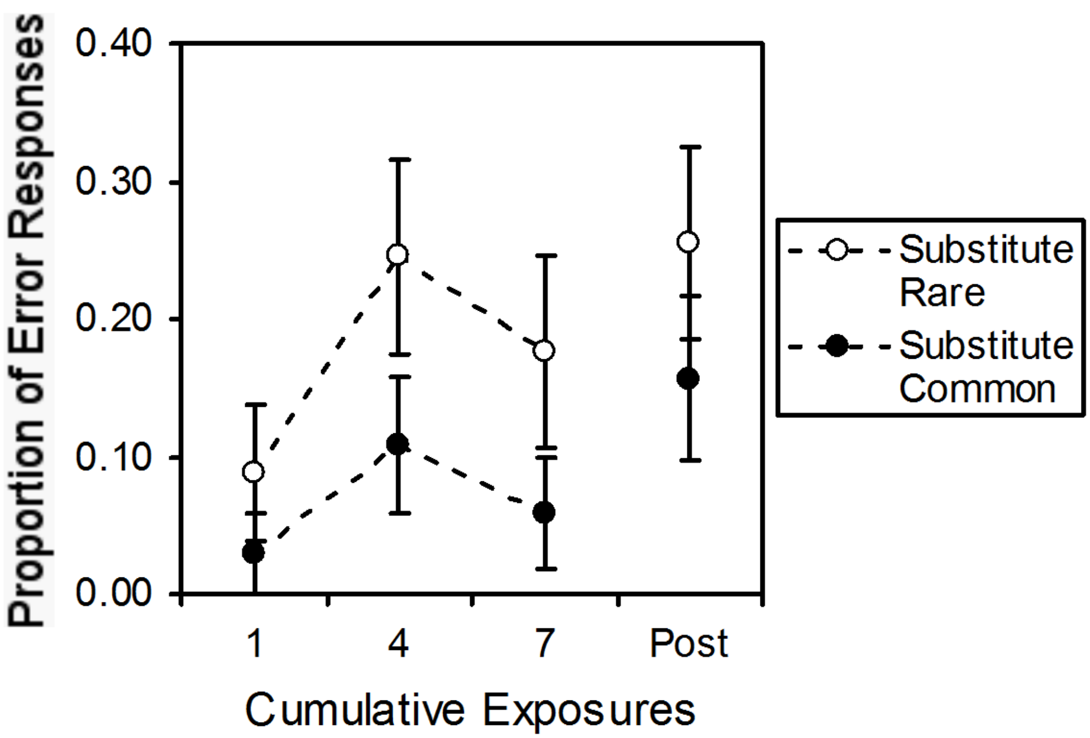
0.00
1
4
7
Post
Cumulative Exposures
Substitute Rare
Substitute Common


Proportion of Error Responses
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1
4
7
Post
Cumulative Exposures
Substitute Rare
Substitute Common