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The effect of probabilistic phonotactics on lexical acquisition

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Abstract

The effect of probabilistic phonotactics on lexical acquisition in typically developing children was examined to determine whether a lexical or sublexical level of language processing dominates lexical acquisition. Sixty-one normally achieving 7, 10, and 13 year-old children participated in a word learning task, involving non-words of varying probabilistic phonotactics. Non-words were presented in a lecture format and recognition memory was tested following a 7 minute filled delay. Results showed that 10 and 13 year-old children recognized more high probability non-words than low probability non-words. In contrast, 7 year-old children showed no consistent effect of probabilistic phonotactics on lexical acquisition. These findings suggest that the sublexical level of processing dominates word learning during the initial phases in older children. This, in turn, raises questions about the mental representations of words and the effect of phonological knowledge on lexical acquisition in young children. Implications of these findings for children with specific language impairment (SLI) are discussed.

Keywords: Language development, phonology, school-age children.

Introduction

Children rapidly acquire a number of words without the benefit of direct instruction. For example, infants are able to recognize previously heard words in new contexts (Jusczyk and Aslin, 1995). Likewise, children between pre-school and sixth grade can associate the phonological form of the novel word with the referent following one exposure (Dickinson, 1984; Dollaghan, 1985; 1987; Heibeck and Markman, 1987). This ability is termed *fast mapping* (Carey and Bartlett, 1978). After this single encounter with a word, the mental representation may be incomplete or inaccurate. Initial representations are thought to be retained over time (Dickinson, 1984) and elaborated with subsequent exposures to the same word (Carey, 1978). Pre-school and school-age children are also able to learn novel words encountered

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in discourse when minimal cues are present to support the link between novel forms and referents (Rice and Woodsmall, 1988; Rice, Buhr, and Nemeth, 1990; Oetting, Rice, and Swank, 1995). This ability is termed *quick incidental learning* (QUIL; Rice, 1990).

The empirical evidence documenting fast mapping and QUIL suggests that children have remarkably robust lexical acquisition abilities across a variety of tasks. What is less clear is how the structure of the mental lexicon and sensitivity to the characteristics of the native language may influence lexical acquisition. That is, novel words are learned in the context of known words and, for this reason, the organization of these known words in the mental lexicon may determine which words are more readily acquired. This may also have developmental consequences. If the organization of the mental lexicon influences lexical acquisition, then changes in the organization of the mental lexicon could promote changes in lexical acquisition. In addition to this, sensitivity to patterns in the native language may influence lexical acquisition. Some phonological sequences are more common than others are. Consequently, the predictability of the phonological form of a novel word may influence speed of lexical acquisition. In this case, changes in sensitivity to the predictability of sound patterns in the native language may contribute to changes in lexical acquisition. Each of these issues is considered, in turn, and a model of the lexical acquisition process is offered that yields testable hypotheses as the purpose of the present study.

Structure of the mental lexicon

Models of long-term-memory assume two separate storage systems: semantic and phonologic (e.g. Dell, 1986; 1988; Butterworth, 1992; Levelt and Wheeldon, 1994). The *semantic lexicon* contains the abstract representation of a word's meaning and syntactic constraints. Representations in the semantic lexicon are linked to forms in the phonologic lexicon. The *phonologic lexicon*, the focus of the current paper, contains the phonological representation of a word including syllabic, prosodic, and segmental information. The phonologic lexicon is organized so that phonologically similar words are claimed to reside in the same phonological neighbourhood. A *phonologic similarity neighbourhood* is a collection of words that are phonetically similar to each other, only differing by a single sound. The number of words residing in a neighbourhood is referred to as *neighbourhood density*. High density words, then, are words with many phonologically similar neighbours, whereas low density words are words with few neighbours.

Neighbourhood density has been shown to affect processing in adults. Specifically, high density words apparently show a disadvantage relative to low density words. For example, recognition of words from high density neighbourhoods under noise masking conditions is slower and less accurate than recognition of words from low density neighbourhoods (Luce and Pisoni, 1998). Similarly, words and non-words from high density neighbourhoods are slower to be judged as real words or non-words than words from low density neighbourhoods (Luce and Pisoni, 1998; Vitevitch and Luce, 1999). Lastly, words from high density neighbourhoods are repeated more slowly than words from low density neighbourhoods (Luce and Pisoni, 1998; Vitevitch and Luce, 1998; 1999). Across a variety of tasks, high density has an inhibitory effect on processing. Models of word recognition and speech production assume that lexical representations compete during processing (Dell, 1986, 1988; McClelland and Elman, 1986; Norris, 1994; Luce and Pisoni, 1998; Vitevitch and Luce, 1998; 1999). When a word is phonologically similar to many words, as in a high density neighbourhood, it is claimed that competition is greater, producing inhibitory effects on speed of processing.

Studies of adults provide ample evidence that neighbourhood density affects language processing. If the organization of the mental lexicon in children were similar to adults, then one would also expect neighbourhood density to influence language processing in children. Children appear to have relatively small lexical neighbourhoods that increase in density with development (Charles-Luce and Luce, 1990; 1995; Logan, 1992; Dollaghan, 1994). Given the sparseness of lexical neighbourhoods, it is possible that children may have more coarsely coded underlying lexical representations (Charles-Luce, and Luce, 1990; 1995; Logan, 1992). The quality of the lexical representations may differ between children and adults, but the organization seems to be similar. In support of this hypothesis, studies of word recognition show that children, like adults, are less accurate at recognizing words from high density than low density neighbourhoods (Kirk, Pisoni and Osberger, 1995). The structure of the mental lexicon seems to affect processing in children; however, there is no evidence to indicate how neighbourhood density affects lexical acquisition. Based on language processing studies, one might predict that words from high density neighbourhoods would be acquired more slowly than words from low density neighbourhoods, due to the amount of phonological detail needed to differentiate the novel word from its neighbours (but, see Logan, 1992; Jusczyk, Luce, and Charles-Luce, 1994).

Structure of the native language

Languages are characterized by regularities in rhythmic and phonological forms of words. There are two aspects to these regularities: rules and probabilities. Language specific rules define which phones or phonetic sequences are possible in various word positions. The rules that govern the phonological formation of words are referred to as *phonotactic constraints* (Trask, 1996). Probabilities, on the other hand, define which legal forms are more likely and which are less likely to occur in a given language. *Probabilistic phonotactics* refers to the likelihood that a given phonological sequence will occur in a language (Trask, 1996). Probabilistic phonotactics can be decomposed into two types of probabilities. *Positional segment frequency* is the probability that a given phoneme will occur in a specific word or syllable position (Jusczyk *et al.*, 1994). *Biphone frequency* is the probability that a given phoneme will precede or follow another phoneme (Jusczyk *et al.*, 1994).

Like neighbourhood density, phonotactics and probabilistic phonotactics affect processing in adults. There appears to be a processing advantage for phonotactically legal sound sequences and for high probability sound sequences. For example, adults are more accurate at identifying (i.e. transcribing) phonotactically legal non-words than phonotactically illegal non-words (Brown and Hildum, 1956). In terms of probabilistic phonotactics, non-words composed of highly probable phonotactic patterns are repeated more rapidly and more accurately than less probable phonotactic patterns (Vitevitch, Luce, Charles-Luce, and Kemmerer, 1997; Vitevitch and Luce, 1998; 1999). In addition, words high in phonotactic probability are named faster than words low in phonotactic probability (Levelt and Wheeldon, 1994). When taken together, adults seem to be sensitive to both phonotactic constraints and probabilistic phonotactics, with more likely sound patterns providing a processing advantage.

Are children sensitive to phonotactic constraints and probabilities? Previous research indicates that they are and that this sensitivity develops early. Nine month-old infants show preferential listening for phonotactically legal non-words, whereas, 6 month-old infants do not (Friederici and Wessels, 1993; Jusczyk, Friederici, Wessels, Svenkerud, and Jusczyk, 1993). Likewise, 9 month-old infants listen significantly longer to non-words of high phonotactic probability than non-words of low phonotactic probability (Jusczyk *et al.*, 1994). Based on this evidence, sensitivity to phonotactic constraints and probabilities appears to develop during infancy, and has the potential to influence lexical acquisition. It is predicted that words of high phonotactic probability may be learned more rapidly than words of low phonotactic probability because of the predictability of the phonological sequence.

Density/phonotactic probability paradox

The evidence indicating an inhibitory effect of high neighbourhood density and a facilitory effect of high phonotactic probability presents a paradox. Neighbourhood density and probabilistic phonotactics are positively correlated. That is, words with many neighbours tend to be composed of highly predictable sound sequences, rather than less predictable sound sequences. For example, the word 'seat' has many neighbours, such as *scene*, *siege*, *seem*, *seek*, *seal*, *sit*, *set*, sat, *suit*, *cheat*, *sheet*, *heat*, *feet*, *meat*. Moreover, at the segmental level for 'seat', /s/ is common word initially, /t/ is common word finally, and /si/ and /it/ frequently co-occur in English. As in this and other forms, high density words tend to be high in phonotactic probability. How can the effect of high density be inhibitory while the correlated variable, high phonotactic probability, is facilitory? This paradox can be resolved by assuming a lexical and sublexical level of processing, with different variables affecting each level (Levelt, 1989; Levelt and Wheeldon, 1994; Vitevitch and Luce, 1998; 1999). The *lexical level* corresponds to lexical entries in phonologic similarity neighbourhoods. It is hypothesized that processing at the lexical level is influenced by neighbourhood density. The *sublexical level* corresponds to phonemes. Probabilistic phonotactics presumably affect processing at the sublexical level. It is claimed that only one of these two levels will dominate processing in a given task. If the lexical level dominates, then an inhibitory effect of high density/phonotactic probability is expected (Vitevitch and Luce, 1998; 1999). In complement, if the sublexical level dominates, then a facilitory effect of high density/phonotactic probability is predicted (Vitevitch and Luce, 1998; 1999). In support of this hypothesis, the lexical status of the stimulus (i.e. word or non-word) has been shown to influence the effect of density and phonotactic probability on processing. Non-words differ from words in that non-words do not have a representation at the lexical level, but words do. The implication for processing is that inhibition is found for *words* where lexical processing is assumed to dominate, and facilitation is found for *non-words* where sublexical processing is assumed to dominate (Vitevitch and Luce, 1998; 1999). Likewise, processing constraints of a task can determine the dominant level (Vitevitch and Luce, 1999). Lexical decision tasks are thought to invoke lexical processing, producing an inhibitory effect of high density/phonotactic probability for both words and non-words (Luce and Pisoni, 1998; Vitevitch and Luce, 1999).

Model of lexical acquisition

What are the implications of the purported two-level model for lexical acquisition? When a novel word is encountered, it presumably activates both the lexical and sublexical levels. Novel words will not match an existing representation at the lexical level, so the process of establishing a new lexical node is thought to begin. It is likely that the creation of a new lexical entry will begin sooner for novel words from low density neighbourhoods than from high density neighbourhoods. Thus, one prediction that emerges is that a child will acquire new words from low density neighbourhoods more rapidly due to this advantage at the lexical level. The reason is that novel words from low density neighbourhoods have been judged as 'absent' from the lexicon more rapidly than novel words from high density neighbourhoods (Luce and Pisoni, 1998; Vitevitch and Luce, 1999). From this point forward, then, the sublexical level of processing is thought to dominate the lexical acquisition process. Processing at the sublexical (or phonemic) level is presumably used to create the mental representation at the lexical level. It is predicted that a more accurate and complete representation will be established for a high probability than a low probability novel word. The reason is that sublexical processing of high probability novel words is facilitated relative to low probability novel words due to the predictability of the phonological sequence.

The hypothesis that emerges from the above model is that the sublexical level of processing dominates lexical acquisition due to its role in establishing the substantive details of the mental representation. Following from this, one prediction then is that the influence of neighbourhood density will be minimal, while the effect of probabilistic phonotactics will be strong in children's word learning. In other words, it is predicted that more high probability/density non-words will be learned following limited exposure than low probability/density non-words. Given that sensitivity to phonotactic probability emerges by 9 months of age, it is hypothesized that there will be no change in the effect of phonotactic probability on lexical acquisition among older and younger school-age children.

Method

Participants

Sixty-one normally achieving 7, 10 and 13 year-old students from a local US public school were recruited by public announcements to their parents and guardians. Children who were eligible to participate: (a) secured parental consent; (b) were identified as typically developing by teacher and parent report; (c) were monolingual with no formal instruction in a second language; (d) passed a hearing screening conducted by the school; (e) obtained a scaled score of 7 or greater on the *Detroit Test of Learning Aptitude-3rd edition*, subtest of Word Opposites (DTLA-WO), where 7 corresponds to 1 standard deviation below the mean (Hammill, 1991). The DTLA-WO served as a screening measure of general vocabulary and metalinguistic skill and was included to corroborate parent and teacher report. Constraints associated with testing in the schools dictated that the DTLA-WO items be administered only until the 7 year-old children met the criteria corresponding to a standard score of 7. In all, 23 7 year-old students, 20 10 year-old students, and 18 13 year-old students participated in the investigation. Characteristics of participating students are summarized in table 1.

Stimuli

Non-words were constructed such that there were six disyllabic items of high phonotactic probability/density and six disyllabic items of low phonotactic probability/density, as shown in table 2. Syllables of high and low phonotactic probability were taken from Jusczyk *et al.* (1994). Two measures were used to evaluate phonotactic probability in Jusczyk *et al.* (1994): positional segment frequency and biphone frequency. The high and low probability consonant-vowel-consonant (CVC) syllables from Jusczyk *et al.* (1994) were joined to create two-syllable non-words, consisting of either two high probability adjoined syllables or two low probability adjoined syllables. First and second syllables were chosen for concatenation, so that the final consonant of the first syllable and the initial consonant of the second syllable were identical (i.e., $C_1V_1\mathbf{C}_2 + \mathbf{C}_2V_2C_3$). Thus, all disyllabic non-words had an open first syllable and a closed second syllable (i.e. $C_1V_1.C_2V_2C_3$). Table 3 shows

Table 1. *Participant characteristics*

Group		Age	DTLA-WO[a] percentile	DTLA-WO[a] standard score
7 year-olds	Mean	7;3	N/A[b]	N/A[b]
	Range	6;9–8;1		
10 year-olds	Mean	10;3	75	12
	Range	9;9–11;3	37–95	9–15
13 year-olds	Mean	13;1	72	12
	Range	12;8–14;1	50–91	10–14

[a]*Detroit Test of Learning Aptitude*, subtest of Word Opposites (Hammill, 1991).
[b]DTLA-WO used as a screening measure; exact scores not available.

Table 2. *Auditory and visual stimuli*

Semantic pair	Semantic category	Picture 1	Low phonotactic probability non-word	Picture 2	High phonotactic probability non-word
1	Musical instruments	Lyre (p. 535)[a]	[tʃeθəz]	Zither (p. 535)[a]	[kisɑɪm]
2	Office supplies	Stamp rack (p. 516)[a]	[giʃɑɪb]	Bill file (p. 516)[a]	[sɑɪpəm]
3	Garden tools	Weeding hoe (p. 266)[a]	[kɑɪðəv]	Lawn aerator (p. 266)[a]	[vetəl]
4	Bolts	Expansion bolt (p. 276)[a]	[ʤegɑɪb]	Toggle bolt (p. 276)[a]	[fiked]
5	Vehicles	Grader (p. 784)[a]	[fɑɪðig]	Scraper (p. 784)[a]	[pebɑɪn]
6	Eyewear	Scissor glasses (p. 377)[a]	[zigeʒ]	Lorgnette (p. 377)[a]	[tɑɪsiv]

[a]*Macmillan ffisual Dictionary* (1997).

Table 3. *Computational analysis of non-word stimuli*

Syllable		Positional segment frequency: Low phonotactic probability	Positional segment frequency: High phonotactic probability	Biphone frequency: Low phonotactic probability	Biphone frequency: High phonotactic probability
First	*M*	0.0635	0.0973	0.0006	0.0019
	SD	0.0354	0.0327	0.0005	0.0009
Second	*M*	0.0663	0.1693	0.0013	0.0056
	SD	0.0118	0.0127	0.0003	0.0015

the results of computational analysis of the subset of syllables from Jusczyk *et al.* (1994) used in the current study. The correlation between neighbourhood density and phonotactic probability was significant ($r = 0.698$ and 0.838, $p = 0.012$ and 0.001, for first and second syllables respectively). Age of consonant acquisition, as detailed in Smit, Hand, Freilinger, Bernthal and Bird (1990; table 7) was not significantly different between low and high probability non-words ($t(10) = -0.998$, -0.488, -0.498; $p = 0.344$, 0.639, 0.634, for initial, medial, and final consonants, respectively).

The first syllable of the non-word received primary stress. Each phoneme was introduced only once in the word. To decrease the confusability of the non-words within the study, each consonant occurred in initial position only one time within each set of high and low probability non-words. A given phonotactic sequence was used in only one non-word. Vowel patterns across the two syllables in a non-word were never repeated within a set of high probability or low probability non-words. For example, CV_1CV_2C occurred in only one word in the set.

The 12 non-words were randomly paired with 12 pictures (see table 1) from the *Macmillan ffisual Dictionary* (1997). The pictures were previously judged to be unknown to children (Storkel, 1998). There was no significant difference in picture recognition between the pictures paired with low or high probability non-words ($t(10) = 1.090$; $p = 0.301$). Pictures were selected in pairs, such that two pictures were taken from the same semantic category in an attempt to equate the semantic characteristics across the two levels of phonotactic probability. The non-word picture pairs were randomly assigned to two test lists, consisting of six items each and balanced in probabilistic phonotactic characteristics.

Procedures

The study was conducted in the subjects' classroom. A group of approximately 15 students participated at one time. Three adults, including the classroom teacher, were present during data collection. To guard against collaboration during responding, students were seated apart, with one desk or seat between each participant, and two different versions of the response form were used. Auditory stimuli were presented live-voice and visual stimuli, by overhead projector.

Pre-training

The pre-training procedure introduced the recognition test procedure. Participants matched six personal names to six corresponding photographs. The response form displayed the six photographs, each associated with a letter, and numbered response blanks. Children were to write the letter corresponding to their response choice in the appropriate blank. The pre-training also prepared the children for the experimental task. Three non-words and three novel objects constructed using the same criteria as the experimental stimuli were presented using the same format as the experimental task. All classes demonstrated compliance with the behavioural expectations for the task by listening to the content and then making verbal responses when prompted.

Experimental phase

The experimental non-words were presented in two sets of six items. Test lists were counterbalanced across classrooms within each grade to control for order effects. Participants were told that they would be learning about unusual objects used in two different cities. The two cities were given non-word names and shown on a map. Participants were instructed that they would take a test following the lecture about each city. During the exposure phase, the participants saw the picture of the non-word object projected onto a screen as the experimenter named and defined the non-word. Transitions between successive items were marked by an introductory sentence providing general semantic information. The appendix shows the script used, along with the definition forms.

Following presentation of the six non-words in a blocked set, there was a 7-minute filled delay consisting of responses to metacognitive questions as reported in Storkel (1998). After this delay, recognition testing was conducted. Non-words were presented, and the participants performed a matching task as described in the pre-training procedure. To minimize process-of-elimination responding, one unfamiliar non-word was included in the test set. Participants were given a response choice 'Not one of the words I heard'. Following a 2-minute filled delay consisting of generation of antonyms; the exposure and recognition testing procedures were repeated for the second set of six non-words. The entire experimental session lasted approximately 45–60 minutes.

Experimental sessions were audiotaped and later transcribed by a research assistant to compute procedural reliability of the live-voice presentation. Mean reliability of non-word productions across classes was 99% agreement between the experimenter and the research assistant.

Analysis

The two independent variables of interest were Phonotactic Probability (low, high) and Age (7, 10, 13) as well as the interaction Phonotactic Probability × Age. Although the effect of phonotactic probability on lexical acquisition was the theoretical motivation for this study, it is possible that semantic factors may influence lexical acquisition. In this way, semantic variables might influence or obscure the effect of phonotactic probability. As a result, Semantic Pair (musical instruments, office supplies, garden tools, bolts, vehicles, and eyewear) was included in the analysis as a potential effect modifier. The dependent variable was accuracy of recognition responses for each individual word, which is a binary value (correct/incorrect). Given that the dependent variable is binary, logistic regression was used to analyse the data. One of the underlying assumptions of logistic regression is that the responses are independent (Kleinbaum, Kupper, and Muller, 1988). That is, apart from any similarity due to common values of the independent variable, no group of observations is more closely related than any other group. In the current study, responses to multiple non-words were elicited from each participant (i.e. repeated measures), violating the independence assumption. For this reason, a generalized estimating equation (GEE) method was used to guard against type I error (DeRouen, Mancl, and Hujoel, 1991). With the GEE method, responses between participants are assumed to be independent and responses from the same participant are assumed to be dependent. An exchangeable correlation structure was used to model the dependence of responses by the same subject. In an exchangeable correlation structure, the pairwise correlation between responses from the same participant is assumed to be equivalent.

An additional benefit of logistic regression is that the slope estimates for the independent variables have an odds ratio interpretation that can be used to assess the predicted magnitude of the effect of a given independent variable. For the current study, the *odds in favour of success* are defined as the ratio of the probability of learning the non-words divided by the probability of not learning the non-words within a given level of phonotactic probability (Rosner, 1995, Definition 10.6). The *odds ratio*, then, relates the odds of learning the high phonotactic probability non-words relative to the odds of learning the low phonotactic probability non-words (Rosner, 1995, Definition 10.7). In this way, the odds ratio provides information regarding how much more likely word learning is for high probability non-words than for low probability non-words. An odds ratio of 1 indicates that word learning is equally likely for high and low probability non-words. An odds ratio greater than 1 indicates that successful acquisition of the high probability non-words is more likely than the low probability non-words. Conversely, ratios less than 1 indicate that word learning is less likely in the high phonotactic probability condition than in the low phonotactic probability condition.

Results

The current study was designed to test the hypothesis that the sublexical level of processing dominates lexical acquisition in children. It is predicted that more high probability non-words would be learned than low probability non-words. Note that if the lexical level of processing dominates word learning instead, then the opposite outcome is expected. Further, it is hypothesized that there would be no interaction of phonotactic probability and age, because sensitivity to phonotactic probability is presumably acquired in infancy. In contrast, if the lexical level dominates word learning, then an interaction between age and phonotactic probability might be expected. In this case, lexical growth may influence word learning. The statistical analysis of Phonotactic Probability and Age is considered first to test these word learning and developmental hypotheses. To further explore the effect of phonotactic probability on word learning, the potential modification of Phonotactic Probability by Semantic Pair and the size of the effect of Phonotactic Probability are each considered, in turn.

The effect of Phonotactic Probability and Age on lexical acquisition was analysed using logistic regression. The results of the analysis are displayed in table 4. There was a significant main effect of Phonotactic Probability and a significant interaction of Phonotactic Probability and Age. Figure 1 and table 5 display the percentage of children who correctly recognized the non-words by Phonotactic Probability and Age. As shown in figure 1 and table 5, children in the Age 7 group showed no

Table 4. *Results of the logistic regression analysis*

Predictor variable	β estimate	Standard error	Z	p-value
Phonotactic probability	1.0179	0.4359	2.3350	0.0195*
Age 7	− 0.5681	0.3641	− 1.5600	0.1187
Age 10	− 0.3168	0.3769	− 0.8407	0.4005
Age 13	0.0000	0.0000	0.0000	0.0000[a]
Semantic Pair 1	− 1.0844	0.3553	− 3.0520	0.0023*
Semantic Pair 2	− 1.2644	0.3256	− 3.8840	0.0001*
Semantic Pair 3	− 1.0449	0.2978	− 3.5080	0.0005*
Semantic Pair 4	− 0.7974	0.2802	− 2.8450	0.0044*
Semantic Pair 5	− 0.2115	0.2455	− 0.8615	0.3890
Semantic Pair 6	0.0000	0.0000	0.0000	0.0000[b]
PP × Age	0.1147	0.0545	2.1058	0.0352*
PP × Sem	− 0.3572	0.1000	− 3.5710	0.0004*

Note: Semantic pair 1 = musical instrument; semantic pair 2 = office supplies, semantic pair 3 = garden tools, semantic pair 4 = bolts, semantic pair 5 = vehicles, semantic pair 6 = eyewear.
*Statistically significant result; $p < 0.05$.
[a]The analysis of the categorical variable age involved the comparison of each age to an arbitrarily chosen reference level (i.e. Age 13). Thus, age 13 was compared to itself resulting in the value 0.0000 for each parameter.
[b]The analysis of the categorical variable semantic pair involved the comparison of each level of semantic pair to an arbitrarily chosen reference level (i.e. Semantic Pair 6). Thus, semantic pair 6 was compared to itself resulting in the value 0.0000 for each parameter.

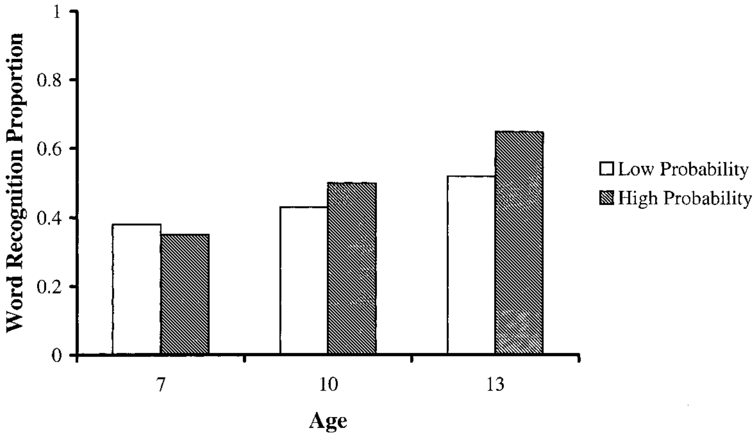

Figure 1. *The percentage of children correctly responding to low probability non-words (light bar) and high probability non-words (dark bar) for 7, 10, and 13-year-old children.*

difference between low and high probability non-words. This result was not predicted because it was assumed that one level of processing would dominate lexical acquisition, leading to an advantage for either high or low probability non-words. In contrast, children in the Age 10 and Age 13 groups learned more high probability non-words than low probability non-words. This is the predicted result when sublexical processing dominates lexical acquisition.

Phonotactic probability appeared to influence lexical acquisition; however, it is possible that the effect of phonotactic probability might be obscured or altered by semantic influences. For this reason, Semantic Pair was included in the regression

Table 5. *Proportion of children who correctly responded to each non-word by Semantic Pair, Age, and Phonotactic Probability*

	Age 7		Age 10		Age 13			All Ages	
	Low	High	Low	High	Low	High		Low	High
Pair 1:	0.39	0.30	0.40	0.60	0.50	0.78	*M*	0.43	0.54
Instruments							*SD*	0.06	0.28
Pair 2:	0.13	0.48	0.35	0.40	0.44	0.67	*M*	0.30	0.51
Office supplies							*SD*	0.16	0.24
Pair 3:	0.26	0.48	0.30	0.50	0.22	0.72	*M*	0.26	0.56
Garden tools							*SD*	0.04	0.27
Pair 4:	0.52	0.26	0.30	0.45	0.61	0.44	*M*	0.48	0.38
Bolts							*SD*	0.16	0.21
Pair 5:	0.43	0.43	0.45	0.55	0.61	0.72	*M*	0.49	0.56
Vehicles							*SD*	0.10	0.27
Pair 6:	0.57	0.13	0.80	0.50	0.72	0.56	*M*	0.69	0.38
Eyewear							*SD*	0.12	0.25
All pairs									
M	0.38	0.35	0.43	0.50	0.52	0.65	*M*	0.44	0.49
SD	0.16	0.14	0.19	0.07	0.17	0.13	*SD*	0.15	0.09

M = mean; *SD* = standard deviation.

analysis as a potential effect modifier. The analysis showed a significant main effect of Semantic Pair, as well as a significant interaction of Semantic Pair and Phonotactic Probability (refer to table 4 for statistical parameters). Figure 2 and table 5 show the percentage of children accurately recognizing low and high probability non-words for each semantic pair. From this, it can be seen that an advantage for high probability non-words was observed for four of the six semantic pairs, namely musical instruments, office supplies, garden tools, and vehicles. In contrast, an

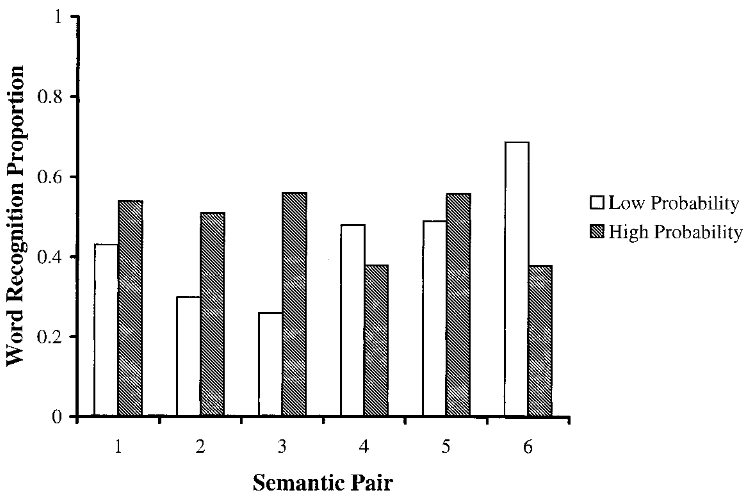

Figure 2. *The percentage of children correctly responding to low probability non-words (light bar) and high probability non-words (dark bar) for semantic pair 1 (musical instruments), semantic pair 2 (office supplies), semantic pair 3 (garden tools), semantic pair 4 (bolts), semantic pair 5 (vehicles), and semantic pair 6 (eyewear).*

advantage for low probability non-words was observed in only two semantic pairs, bolts and eyewear. Taken together, the effect of phonotactic probability appears to be relatively consistent across the levels of semantic pair.

Statistical analysis revealed that phonotactic probability appeared to reliably influence lexical acquisition. It is also important to consider the size of the effect of phonotactic probability. To this end, odds ratios relating the odds of learning a high probability non-word to the odds of learning a low probability non-word were computed to quantify the predicted influence of phonotactic probability on lexical acquisition. Table 6 displays the odds ratios for each level of Phonotactic Probability, Age, and Semantic Pair. For the Age 7 group, the mean odds ratio across the semantic pairs was 1.10 (range = 0.37–2.18), indicating that high probability non-words and low probability non-words were equally likely to be acquired. In contrast, the Age 10 group was 1.50 times (range = 0.53–3.07) more likely to acquire a high probability non-word than a low probability non-word. The odds ratio was larger for the Age 13 group, which was twice (range = 0.74–4.34) as likely to acquire a high probability non-word than a low probability non-word. The means and ranges of the odds ratios suggest that, although the effect of phonotactic probability on lexical acquisition was statistically reliable, the size of the effect was modest in some cases.

Discussion

The current study addressed questions regarding the dominant level of processing in lexical acquisition in children. It was hypothesized that sublexical processing was essential in establishing the initial mental representation, and that lexical processing was less influential. For this reason, a facilitory effect of high phonotactic probability was predicted. The results supported this prediction. On the whole, children learned more high probability non-words than low probability non-words. The advantage of high probability non-words over low probability non-words was observed in four of the six semantic pairs, although this advantage was modest. At the onset of the study, no developmental change was predicted in the high probability advantage across age in school-age children; however, the data are counter to this prediction. While 10 and 13 year-old children showed an effect of phonotactic probability,

Table 6. *Odds ratios relating the likelihood of learning high phonotactic probability non-words to low phonotactic probability non-words for each age group and each semantic pair**

	Age 7	Age 10	Age 13
Pair 1: Instruments	2.18	3.07	4.34
Pair 2: Office supplies	1.53	2.16	3.05
Pair 3: Garden tools	1.08	1.52	2.14
Pair 4: Bolts	0.76	1.06	1.51
Pair 5: Vehicles	0.53	0.75	1.06
Pair 6: Eyewear	0.37	0.53	0.74
Mean for all pairs	1.10	1.50	2.14

* If the odds ratio = 1, then acquisition of high and low probability non-words is equally likely. If the odds ratio > 1, then acquisition of high probability non-words is more likely than acquisition of low probability non-words. If the odds ratio < 1, then acquisition of high probability non-words is less likely than low probability non-words.

7 year-old children did not, suggesting a developmental progression. The implications of each of these findings are considered in the sections that follow.

Effect of phonologic form

Taken together, the findings of this study suggest that variables affecting the formation of mental representations constrain lexical acquisition. Based on the model put forth in the introduction of this study, sublexical variables arguably affect a child's ability to extract and represent the phonological form of a novel word. Thus, it is possible that other phonological variables, such as prosody, word length, and syllable structure, influence lexical acquisition. For example, words with more likely stress patterns, as in the dominant trochaic pattern of English, may be easier to learn than words with less likely stress patterns. Shorter words and words with less marked syllable structure are also predicted to be easier to acquire because of facilitation at the sublexical level of processing. These predictions, based on sublexical dominance in word learning, are counter to predictions based on lexical dominance. For this reason, further investigation of the effects of phonological form on lexical acquisition may yield additional evidence regarding the dominant level of language processing.

The hypothesis that sublexical variables affect the formation of lexical representations has implications for children with specific language impairment (SLI). Children with SLI appear to acquire novel words more slowly than their typically developing peers (Rice *et al.*, 1990; Oetting *et al.*, 1995). Perceptual processing deficits (Ellis-Weismer and Hesketh, 1996; 1998) and memory deficits in the storage of phonological representations (e.g. Gathercole and Baddeley, 1990; Montgomery, 1995) have been implicated as potential causes of this delay in lexical acquisition. These theories suggest the possibility that the sublexical level of processing may be at the root of lexical acquisition deficits in children with SLI. Examining the effect of phonotactic probability on lexical acquisition in children with SLI might provide further support that the locus of the deficit is at the sublexical level. One possibility is that children with SLI may not learn the probability of occurrence of phonological sequences. In this case, children with SLI would show no difference in rate of acquisition of high and low probability words. Under this hypothesis, slowed lexical acquisition in children with SLI may, in part, be attributable to an inability to capitalize on the phonological regularities of the language. In contrast, if children with SLI do learn phonologic distributional regularities, then high probability words may show an even greater advantage in lexical acquisition for children with SLI. In this scenario, it is hypothesized that phonotactic probability would provide compensation for deficits in perceptual processing or working memory. A final possibility is that children with SLI might demonstrate a low probability advantage in lexical acquisition. Because of deficits in encoding and storing of phonologic forms, words that are distinct from other words may be more easily acquired due to decreased confusion with other similar forms. Taken together, the study of the effect of phonotactic probability on lexical acquisition may provide additional evidence regarding the factors that contribute to reportedly poor lexical acquisition in children with SLI.

The effect of phonotactic probability on lexical acquisition was modest but reliable in this study. When phonotactic probability was examined by aggregating across the levels of semantic pairs, minimal effects were apparent. Likewise, when phonotactic probability was examined within non-words matched on semantic variables, a modest consistent influence was detected. The observed interaction between phonotactic probability and semantic pair suggests that lexical acquisition may be influenced by multiple stimulus factors. If this is true, it may be difficult to find a single factor that strongly or uniquely influences lexical acquisition. For this reason, even modest effects may be informative when consistent. Further empirical investigations that provide estimates of odds ratios may aid in disentangling the complex factors that contribute to lexical acquisition.

There are two other factors, exposures and type of testing, that may further account for the modest effect of phonotactic probability in this study and also contribute to a theoretical understanding of the nature of this effect. In the current study, learning was sampled after a series of exposures to a set of words. This sampling after numerous exposures may actually have underestimated the effect of phonotactic probability, potentially accounting for the modest differences observed in this study. If learning had been evaluated after one exposure, instead, the results may have revealed a larger effect of phonotactic probability. The advantage of high probability words may, thus, be more robust during the fast mapping period. The reason for this is that a non-word is hypothesized to eventually form a lexical representation and achieve ‘word’ status during learning. When a lexical representation is firmly established for a non-word, sublexical processing presumably becomes less influential than lexical processing. Given this hypothesis, phonotactic probability should be highly influential initially after minimal exposure, but the effect of phonotactic probability should dissipate as the lexical representation strengthens and becomes dominant. Further investigation of the effect of probabilistic phonotactics on word learning across exposures may lend support to this hypothesis.

The type of testing used to examine word learning may also alter the effect size of phonotactic probability. The current study relied on comprehension testing as an index of lexical acquisition. In this case, the investigator supplied the phonological form of the novel word, and the child identified the referent from a field of choices. If a testing procedure that required the child to identify or produce the phonological form had been used, a more robust advantage of high phonotactic probability might have been observed. It is thought that sublexical processing has a greater effect on establishing the lexical representation than on creating the semantic representation. For this reason, a testing procedure that places greater demands on the newly formed lexical representation (i.e. the phonological form of the novel word) may be a more sensitive measure of the effect of phonotactic probability on lexical acquisition. Future studies using production or phonological recognition testing may reveal a more robust effect of phonotactic probability and provide further support for the importance of sublexical processing in establishing lexical representations.

The effect of phonotactic probability was not demonstrated for two of the six semantic pairs, namely, semantic pairs 4, bolts, and 6, eyewear. Given the host of factors that could potentially influence lexical acquisition, one possible explanation for this result is that factors other than phonological form, such as semantic content, influenced learning. While equating semantic and syntactic factors across the two levels of phonotactic probability was attempted, it is possible that this attempt was not completely successful. Other explanations cannot be ruled out. Inclusion of the semantic pair variable in the statistical analysis allowed for comparison between individual non-words differing in phonotactic probability. More specifically, the difference in phonotactic probability between the non-words was preserved across semantic pairs. It is possible that some of these non-word pairs differed on another variable, while others did not, creating the observed inconsistency. This possibility was explored *post hoc* for two variables: age of consonant mastery and lexicality of the initial syllable. First, while age of consonant mastery was not significantly different for low and high probability non-words when analysed as a group, differences in this variable did fluctuate across semantic pairs. Age of consonant mastery did not appear to differ systematically across the semantic pairs in a way that would predict the anomalous performance on semantic pair 4 and 6. More specifically, it was not the case that the low probability non-word of pairs 4 and 6 were composed of early acquired sounds and the high probability non-words were composed of later acquired sounds, with all other pairs showing the reverse trend.

In addition, the lexical status of the first syllable varied across the non-words (refer to table 1). Two low probability non-words had first syllables corresponding to the letter names 'j' and 'z' (US pronunciation [zi]). Five high probability non-words had real word first syllables, namely, 'key', 'sigh', 'fee', 'pay', and 'tie'. Note that one of the real word syllables in the high probability non-word set, 'fee', was of low familiarity for adults and one, 'sigh', was of low frequency. Thus, it is likely that two of the five real word syllables in the high probability non-word set were unknown to children. This difference in lexicality does not seem to account for the main effect of phonotactic probability. As an illustration, the facilitory effect of high phonotactic probability was observed in non-words without lexicalized first syllables, as seen for the non-words associated with the garden tools (pair 3). Likewise, the advantage of high phonotactic probability was observed in non-words with lexicalized first syllables likely to be unknown to children, as in the office supply non-words (pair 2). It is the case, however, that the low probability non-words in the anomalous semantic pairs (pair 4 and 6) were the two low probability non-words with first syllables corresponding to names of letters (i.e. 'j' and 'z'). It may be that the lexical status of the first syllable, rather than the semantic content associated with the non-word, caused the inconsistencies in the effect of phonotactic probability. This possibility warrants further investigation as it has implications for the interaction of derivational morphology and phonotactic probability in lexical acquisition.

Developmental changes

The lack of an effect of phonotactic probability for the 7 year-old children was not anticipated. A theoretical explanation for this phenomenon is that 7 year-old children may have different mental representations than older children and adults (Charles-Luce and Luce, 1990; 1995; Logan, 1992). Logan (1992) suggested that children might code phonological lexical representations in terms of manner, rather than phonemes, which is the assumed adult coding system. Thus, computations of density and phonotactic probability based on adult phonemically-based representations may not accurately reflect the structure of the child's mental lexicon. Under this assumption, it is possible that the low and high probability non-words were misclassified in this experiment relative to the youngest children's language system. For this reason, it may be advantageous to be able to verify phonotactic probability/density for a given child, although the feasibility of this may be prohibitive. Likewise, further investigation of the coding of lexical representations in children would provide evidence regarding the validity of using phonotactic probability/density calculations based on adult representations with young children.

An alternative to the theoretical account of the age-related differences is based on other associated age-related differences in three areas, namely, school experience, memory and language development, and phonological acquisition. In terms of school experience, the non-word presentation method may have been less familiar to 7 year-old children. These young children may not have encountered the type of lecture and test procedure used in the current study a sufficient number of times; whereas it is quite likely that this procedure was routine for 10 and 13 year-old children. Thus, the 7 year-old children may have been put at a disadvantage by the procedure, perhaps being unable to comply with the directions, attention, or memory demands of the procedure. As a result, the findings may not accurately reflect their underlying abilities. Perhaps, the 7 year-old children may have shown a consistent effect of phonotactic probability if a more familiar paradigm, such as verbal or video presentation of a story, had been used.

Relatedly, the 7 year-olds may have performed differently from the two groups of older children due to memory or language limitations. Unfortunately, no measures of memory or language were taken to explore this hypothesis. Exact DTLA-WO scores were not obtained due to constraints of the school environment. While differences in memory or language processing may account for the overall poorer word learning performance in the 7 year-old group, these variables may not also account for the lack of an effect of phonotactic probability. Recall that even infants are presumably sensitive to phonotactic probability in language processing tasks (Jusczyk et al., 1994). Likewise, in short-term memory tasks, 7 and 8 year-old children show superior recall for high probability non-words over low probability non-words (Gathercole, Frankish, Pickering, and Peaker, 1999). Further information regarding the developmental course of the effect of phonotactic probability on language and memory is needed to determine if these factors can explain the observed developmental differences in lexical acquisition.

A third age-related difference is that the 7 year-old children may not have had the same phonological knowledge as the 10 and 13 year-old children. It was hypothesized that all the children in the study would have a fully-developed phonological system. Although the 7 year-old children may have correctly articulated all the phonemes in the ambient language, it is possible that they were more sensitive to phoneme differences across the non-words. In support of this hypothesis, the 7 year-old children tended to provide more correct responses to non-words composed of late acquired consonants in word-initial position, that is consonants mastered between the ages of 5;6 and 8;0 (Smit, Hand, Freilinger, Bernthal and Bird, 1990). On average, 49% (range 39–57%) of the 7 year-old children responded correctly to non-words with word initial late acquired sounds, whereas only 28% (range 13–43%) responded correctly to non-words with word initial early acquired sounds. The effect of age of consonant mastery on lexical acquisition was not seen for medial or final consonants. These findings suggest that later acquired consonants, specifically in the initial word position, may have been more salient for the young children than the two groups of older children. The fact that only phonemes in the initial position influenced lexical acquisition may be indicative of the relative importance of word initial sounds in lexical organization and perception. Note that Stoel-Gammon (1998) also found a strong correlation between the initial target phonemes of words and productive phonology in 3 year-old children, but a weaker correlation between the lexicon and productive phonology for word final phonemes. Based on these data, it seems plausible that lexical acquisition in younger children may be influenced by characteristics of individual phonemes, especially those in initial position; whereas older children appear to be immune to such phoneme differences. For this reason, it will be important to control the phonemic realization of lexical and sublexical variables such as density and probabilistic phonotactics in future studies with children under the age of 7.

Conclusion

As evidenced by the discussion, many questions remain to be addressed, opening a potentially fruitful line of investigation. Relative to theories of lexical acquisition, further evidence is needed to support the dominant contribution of sublexical processing to the formation of mental representations. In addition, the effect of number of exposures on the modification of the advantage of high probabilistic phonotactics on lexical acquisition has implications for conceptualizations of fast mapping. In terms of development, there is a need to examine differences in mental representations across ages to evaluate the claim that children may have more coarsely coded lexical representations. Likewise, to establish the effect of phonotactic probability on lexical acquisition in younger children it will be necessary to evaluate the possibility that different variables affect word learning in young children. In complement, the effect of phonological development on lexical acquisition warrants investigation, as phonological knowledge may alter the effects of other phonological variables. Together, these issues outline an important course of research that is likely to reveal how mental representations change over time and the effect on lexical acquisition.

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Appendix: Stimuli protocol

Sentence type	Sentence form	Example
Transition sentence	In *name of city* they like to ______ .	In [pimən] they like to plant things.
Label	This is a *non-word*.	This is a [vetəl].
Category	A *non-word* is a type of *category*.	A [vetəl] is a type of gardening tool.
Function	A *non-word* is used for *function*.	A [vetəl] is used for softening dirt.
Reminder	Remember, it's a *non-word*.	Remember, it's a [vetəl].
Delayed imitation	What is it? (choral response).	What is it?
Confirmation	It's a *non-word*.	It's a [vetəl].