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Differential Difficulty in the Acquisition of Second Language Phonology[1]

ELLEN BROSELOW & ZHENG XU*

ABSTRACT

This paper reports on Mandarin speakers' acquisition of English final voiced and voiceless obstruents and final labial nasals, none of which occur in Mandarin codas. The leamers' production patterns are compared with a simulation using the Gradual Leaming Algorithm (Boersma & Hayes 2001). We dernonstrate that when the Mandarin Chinese rankings are assumed as the initial state and this system is provided with representative English input, the GLA correctly models the order of acquisition of obstruent codas (voiceless before voiced). However, the GLA also predicts that voiced obstruent codas should be acquired before coda labials, which are less frequent than voiced obstruents in English. This prediction is not bome out; speakers made fewer errors with final labial nasals than with final voiced obstruents. We argue that Mandarin speakers' native language perception grammar makes perception of final obstruents more difficult than perception of final nasals, and conclude that the Mandarin learners' pattern can be understood with reference to perceived rather than absolute frequency of input structure types.

KEYWORDS: Second Language Acquisition, Acquisition of Coda Contrasts, Gradual Learning Algorithm, Mandarin Codas.

* *Address for correspondence:* Ellen Broselow and Zheng Xu, Stony Brook University (SUNY), Department of Linguistics, Stony Brook, NY 11794-4376, USA. E-mail: ellen.broselow@sunysb.edu, xuz1014@yahoo.com.

I. BACKGROUND: ACQUISITION OF SECOND LANGUAGE PHONOLOGY

It has long been recognized that certain foreign language structures may be more difficult to acquire than others, even when both types of structure are equally new to learners. For example, learners whose native language (such as Mandarin Chinese or Tswana) has no obstruents in coda position are often more successful in producing voiceless obstruent codas than voiced obstruent codas in the target language, even though both structures are equally new for the leamer (Wissing & Zonneveld 1996, Grijzenhout & van Rooij 2000, Eckman 1981, Flege & Davidian 1984, Flege, McCutcheon, & Smith 1987, Yavas 1994, Wang 1995).

As phonological theory has evolved, increasingly sophisticated accounts of these developmental patterns in second language acquisition have emerged. It was recognized early on that structures that seem to be more difficult to acquire are frequently those that are characterized as more marked (Eckman 1977), where markedness reflects an implicational relationship (the presence of the more marked structure, e.g., voiced obstruent codas, implies the presence of the less marked structure, voiceless obstruent codas). Optimality Theory (Prince & Smolensky 1993, McCarthy & Prince 1993), which assumes a set of universal markedness constraints as part of the grammar ofevery language, offers a way to build markedness principles into the acquisition process. Thus, although the data of Mandarin do not provide the Mandarin speaker with evidence of the relative markedness of voiced vs. voiceless obstruent codas, a universal constraint banning voiced obstruent codas is assumed to be part of the Mandarin speaker's universal endowment (Broselow, Chen & Wang 1998). Furthermore, markedness constraints are assumed to be ranked high in the absence of evidence to the contrary (Hayes 1999, Prince & Tesar 1999). Thus, first language learners begin with the assumption that marked structures such as final voiced obstruents should not occur. The learner of English, who is exposed to such marked structures in the course of language acquisition, will come to rank the markedness constraint NOVOICEDOBSTRUENTCODA below faithfulness constraints demanding preservation of lexical contrasts. But a Mandarin speaker will maintain the default high ranking of this markedness constraint, since it is never violated by input data. This model contrasts with a rule-based model, in which the presence of alternations (such as those traditionally used to motivate a rule of final devoicing in German) would be necessary to motivate a grammar that bans final voiced obstruents. In the constraint-based model, learners will arrive at a grarnmar that allows marked structures only if they are exposed to data in which the marked structures appear (see Yip 1993, Broselow, Chen & Wang 1999 for further discussion of this point).

Optimality Theory provides not only a model of possible grammars, but also a model of how these grammars can be learned. The set of constraints is presumed to be universal, but the rankings specific to individual languages are learned from the data available to the learner. As Broselow (2004) argues, the acquisition of voiceless obstruent codas before voiced obstruent codas can be predicted by a learning algorithm that responds to the frequency of structure types in the input data. Assuming that the universal constraint set includes a general markedness constraint banning all obstruent codas (obeyed in Mandarin Chinese) as well as a more specific

markedness constraint banning only voiced obstruent codas (obeyed in German, Dutch, Russian, etc.), we expect the following possible rankings, predicting possible gramrnars:

(1) Possible Grammars

a. Type 1, No Obstruent Codas (Mandarin)
NoVoicedObsCoda, NoObsCoda » Faithfulness

b. Type 11, Only Voiceless Obstruent Codas (German)
NoVoicedObsCoda » Faithfulness » NoObsCoda

c. Type 111, Both Voiced and Voiceless Obstruent Codas (English)
Faithfulness » NoVoicedObsCoda, NoObsCoda

We can describe the developmental pattern of speakers whose native language is Type 1 and whose target language is Type 111 as movement from the native language grammar through an intermediate stage in which NoObsCoda is demoted below faithfulness constraints, while NoVoicedObsCoda is still highly ranked (Type 11). The faster demotion of NoObsCoda follows from the subset relationship between the two markedness constraints. Clearly, any form that violates the more specific constraint NoVoicedObsCoda will also violate the more general constraint NoObsCoda, but not vice versa. And if, as Boersma & Hayes (2001) argue, the rate at which a markedness constraint is dernoted is a function of the frequency with which the constraint is violated by input structures, then the more general constraint will be demoted more quickly than the more specific (and therefore less frequently violated) constraint (Broselow 2004). Thus an Optimality Theoretic account of acquisition incorporating a learning algorithm sensitive to frequency has the potential to predict which aspects of the foreign language should be more or less difficult for the learner. and to model the developmental course of learning. (See Levelt & van de Vijver 1998 and Boersma & Levelt 1999 for similar claims concerning first language acquisition, and see Prince & Tesar 1999 for an alternative approach to specific/general constraint ranking. Also, see Broselow 2004 for discussion of possible alternative accounts.)

While the frequency-based model appears to successfully predict the developing ranking of the obstruent coda constraints, it remains to be seen whether the relative rankings of markedness constraints which do not bear this relationship can also be predicted. This paper takes up that question. We report on an experimental investigation (Xu 2003) of native Mandarin speakers pronouncing English words containing three coda types that are impossible in Mandarin Chinese: voiceless obstruents [p, t, k], voiced obstruents [b, d, g], and labial nasals [m]. In addition to presenting the experimental results, Xu examined the fit between the performance of these learners and the predictions of the Gradual Learning Algorithm (Boersma 1997, 1998, Boersma & Hayes 2001), which provides an explicit formal model of constraint ranking as a function of the frequency of input structures. Xu found that while the GLA did

indeed correctly model the development of voiceless vs. voiced coda obstruents, the model was less successful in predicting the relative mastery of [m] codas and obstruent codas, predicting the wrong order of acquisition. We consider possible alternative accounts of this pattern, in which a frequency-based account might be either replaced or supplemented by reference to learned articulatory programs, to the role of perception, or to the assignment of weaker status to those markedness constraints that appear to represent language-specific rather than well established universal generalizations. We argue that the tendency of second language learners to filter foreign language structures through their native language perceptual system means that the important factor determining interlanguage constraint ranking is perceived rather than absolute frequency of foreign language structures.

The paper is organized as follows. In section II, we discuss the predictions of a frequency-based learning algorithm for Mandarin speakers' acquisition of English coda structures. We compare the predictions of the simulation with the results of an experiment (Xu 2003) in which Mandarin learners of English produced English words containing final obstruents and nasals in section III. In section IV, we discuss alternative explanations of the patterns found in the experimental data, and summarize our conclusions in section V.

II. A FREQUENCY-BASED MODEL OF SECOND LANGUAGE ACQUISITION

In this section we report on work by Xu (2003) comparing the predictions of the frequency-based Gradual Learning Algorithm (Boersma 1997,1998, Boersma & Hayes 2001) with actual subject productions of second language codas. While Xu's major concern was to model the patterns of variation found in each speaker's production, the model also predicts different rates of mastery of different coda types. Xu (2003) assumed, first, that the learners' initial state grammar was the grammar of their native language, Mandarin Chinese. This assumption seems reasonable for any learner who begins study of a foreign language after acquiring mastery of the first language. and Xu's subjects had begun the study of English no earlier than age 10.

The learning of English by Mandarin speakers provides a good testing ground for predictions concerning differential difficulty of target language structures, since the inventory of coda structures in English is considerably richer than in the subjects' native language:

(2)

Coda Inventories	Mandarin	English
voiceless obstruents	no	yes
voiced obstruents	no	yes
nasals	[n, ŋ]	[m,n, ŋ]
liquids	[ɹ][2]	[ɹ, l]

The absence of obstruent and [m] codas from Mandarin can be accounted for by assuming that markedness constraints banning these structures are more highly ranked in the Mandarin

grarnrnar than in the English grarnrnar. The constraint set assumed by Xu (2003) included the following:

(3) Mandarin Chinese Constraint Set

a. Markedness Constraints

NoVoicedObsCoda: Codas rnay not contain voiced obstruents.

NoObsCoda: Codas rnay not contain obstruents.

No[m]Coda: Codas may not contain labial nasals.[3]

b. Faithfulness Constraints

Dep(V): Don't insert vowels.

Max(Obs): Don't delete obstruents.

Max(Nas): Don't delete nasals.

Ident(Voice): Don't change voicing.

This set of markedness constraints reflects traditional rnarkedness relations. It is assurned that the universal constraint set contains a constraint banning obstruent codas, and a constraint banning voiced obstruent codas, but not the counterpart constraints banning the less marked structures. The absence of a constraint banning sonorant codas reflects the observation by Clernents (1990) that "the preferred syllable type shows a sonority profile that rises maxirnally toward the peak and falls minimally towards the end" (page 301), and the absence of a constraint banning voiceless obstruent codas reflects the well known preference for final voiceless over voiced obstruents. Postulation of a constraint banning [m] codas is harder to justify in terms of universal preferences, and possible reformulations of this constraint will be discussed in section III.

In addition to the constraints in (3), Xu further assumed, following Boersrna & Hayes (2001), that constraint rankings are defined as values on a ranking scale. The ranking value represents the center point of the range of possible rankings that the constraint may take in any given production instance. Therefore, constraints whose ranking ranges overlap may have different rankings at different production instances, leading to variation. To simulate the initial (Mandarin gramrnar) state, Xu (2003) assigned the highest ranking value 100 to the rnarkedness constraints NoVoicedObsCoda, NoObsCoda, and No[m]Coda, which are never violated by Mandarin data. The faithfulness constraints Dep(V), Max(Obs), Max(Nas) and Ident(Voice) were assigned the ranking value 88. The diffcrencc in ranking value between the markedness and faithfulness constraints (12 points) indicates that these constraints do not overlap; that is, each of thc rnarkedness constraints dorninates each of thc faithfulncss constraints in each speech production event." The standard deviation was set at 2.0 (following Bocrsrna & Hayes 2001).

To determine representativc English input to the learner, Xu calculated distributions of coda types based on data extractcd from *the American English Spoken Lexicon* (AESL), an on-

line database containing more than 50,000 commonly used English words. Xu chose the 300 most frequently used words, which appear 129,619,937 times in the corpus, and manually counted the percentages of these words containing different numbers of syllables and different word-final coda types. The resulting distribution is shown below:

(4) Token frequencies of various coda types in English

All Obstruent Codas	43.26%
Voiceless Obstrueiit	19.22%
Voiced Obstrueiit	24.04%
[in] Codas	2.21%
Other	54.50%

Each of the relevant coda types was treated as a separate instance; therefore, a word like CVm.CVb was treated as two inputs, each of which contains either [m] or [b] in the word-final position. The small percentage (4.49 %) of words larger than two syllables in the set of 300 most common words were disregarded.

The modelling process is based on the GLA's basic assumptions: that the learning process is error-driven and that changes in constraint rankings are gradual.' The simulated Mandarin speaker 'hears' each English word and takes it as an input. Then he compares the output generated by his own interlanguage grarnmar with the English word. If the two forms are different, he will adjust his interlanguage grammar so that it will be more likely to produce the correct English form by demoting constraints violated by the correct English form and promoting constraints that favor the correct candidates over his own grammar's output. Each adjustment is moderate and involves a small change in ranking value, determined by the plasticity value assigned to the model. In this case, the plasticity was set at 0.01 (following Boersma & Hayes 2001). As markedness constraints are gradually demoted and faithfulness constraints gradually promoted, the system may arrive at a grammar with very different rankings from those of the initial state, and closer to those of the target language grammar.

II.1. Predictions of the Frequency-Based Model

The frequency hypothesis (see Levelt & Vijver 1998, Boersma & Levelt 1999) predicts that the rate at which a markedness constraint is demoted is a function of the number of input forms that violate it. We therefore expect more frequently violated constraints to be more quickly demoted. Below we see the percentage of the English input forms that violate each of the initially highly ranked markedness constraints:

(5) Percentage of input forrns violating each inarkedness constraint

NoObsCoda	43.26%
NoVoicedObsCoda	24.04%
No[m]Coda	2.21%

Based on these percentages, the GLA predicts that NOOBSCODA should be demoted earlier than NOVOICEDOBSCODA, since the more general constraint is violated considerably more frequently than the more specific constraint. NO[M]CODA is the least frequently violated constraint, and therefore should be the last to be demoted. We therefore expect (abstracting away from the effects of possible rankings of different faithfulness constraints) the following possible grammars:

(6) Predicted outputs with intermediate rankings

Stage 1: NO[M]CODA » NOVOICEDOBSCODA » NOOBSCODA » FAITH

/Vp/ [V] or [VpV]
/Vb/ [V] or [VbV]
/Vm/ [V] or [VmV]

Stage 2: NO[M]CODA » NOVOICEDOBSCODA » FAITH » NOOBSCODA

/Vp/ [Vp]
/Vb/ [V] or [VbV] or [Vp]
/Vm/ [V] or [VmV]

Stage 3: NO[M]CODA » FAITH » NOVOICEDOBSCODA » NOOBSCODA

/Vp/ [Vp]
Nbl [Vb]
Nml [V] or [VmV]

Stage 4: FAITH » NO[M]CODA » NOVOICEDOBSCODA » NOOBSCODA

/Vp/ [Vp]
/Vb/ [Vb]
/Vm/ [Vm]

Thus, a grammar that demotes constraints in proportion to the token frequency of coda structure types leads us to expect that learners who have not completely mastered English should make more errors in producing coda [m] than in producing coda voiced obstruents, and should make more errors in producing voiced than voiceless obstruents.

(7) Predicted order of acquisition of coda types
voiceless obstruents > voiced obstruents > [m]

III. EXPERIMENTAL RESULTS

III.1. Procedures

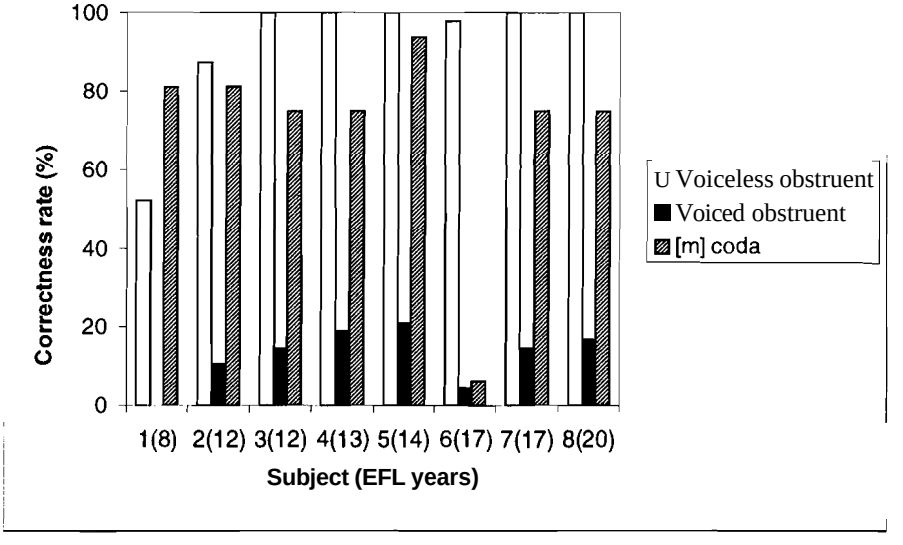
We now examine the results of Xu's (2003) experiment designed to determine the relative mastery of novel English coda types. Eight native speakers of Mandarin Chinese whose only second language was English participated in the experiment. Of the eight participants, seven

were male and one female. their ages ranging from 19 to 33 years. All had been in an English-speaking country for less than two years. and had studied English as a foreign language in China from six to nineteen years. All were enrolled in an ESL class at Stony Brook University at the time of the study.

The experiment was carried out in the sound booth of the phonetics lab at Stony Brook University. The procedure employed was based on that used by Broselow & Finer (1991), which was designed both to deflect subjects' attention from pronunciation and to minimize misperception as a possible source of pronunciation errors. Subjects were told that they would be asked to learn a set of words and their definitions. The words in the learning set, which were either invented or actual (but infrequent) words of English, were presented on a tape read by a native speaker of English. Pretesting determined that subjects were not familiar with any of the words. Subjects were then given a test sheet containing definitions followed by a choice of two possible words in IPA transcription. which all subjects had learned as part of their English instruction in China. For example, the question 'Which word means male sheep?' was followed by the possible responses [fʌp], [tʌp] (see Appendix C). The test included 72 words: 36 monosyllables, 18 bisyllables with initial stress, and 18 bisyllables with final stress. There were 8 words ending in each of the consonants [p, t, k, b. d, g, ni, n, ŋ], balanced across syllable and stress type (see Appendix A. B). Each final consonant was preceded by a lax vowel, and the height of the preceding vowels was balanced across tokens. For each question, subjects chose a response and read it into the tape recorder. In each case, both possible responses had the same rhyme structure; the choice of response was therefore irrelevant for the purposes of the experiment. The process was repeated once for each subject. Four trained phoneticians listened independently to the tapes and then reached agreement on a transcription for each word.

111.2. **Results**

Figure 1 shows the rate of correct production of these three coda types by the subjects.[6] Subjects are numbered based on their EFL experience; Subject 1 has the shortest EFL experience (8 years) while Subject 8 has the longest EFL experience (20 years). We see that voiceless obstruents were produced correctly at least half the time by all subjects (and in all instances by the majority of subjects). Production of final voiced obstruents was much less successful, ranging from 0% correct production to a high of 20.8% correct. These results are therefore consistent with the prediction that word-final voiceless obstruents are acquired earlier than voiced obstruents by Mandarin learners of English. These results are also consistent with previous research; for example, Flege, McCutcheon & Smith (1987) found that Chinese learners of English produced final [b] with less closure voicing than native speakers of English, and Flege (1988a) found that while Mandarin speakers did have longer vowels before voiced than voiceless final stops–a major cue for coda voicing in English–they lengthened considerably less than native speakers of English in the same context.



(8) Figure 1: Phonetic realizations of the three coda types

Figure1 also shows that all subjects were fairly successful in producing final [m]. In fact, all subjects correctly produced more [m] codas than voiced obstruent codas:

(9) Difference in % Correct Production of Voiced Obstruent and [m] Codas.

Subject Number (Years of EFL)	1(8)	2(12)	3(12)	4(13)	5(14)	6(17)	7(17)	8(20)
[m]	81.3	81.3	75.0	75.0	93.7	6.3	75.0	75.0
Voiced Obstruent	0	10.4	14.6	18.8	20.8	4.2	14.6	16.7
Δ	81.3	70.9	60.4	56.2	72.9	2.1	60.4	58.3

Thus, while the subjects' performance was consistent with the predictions of the frequency-based analysis with respect to production of voiced vs. voiceless obstruent codas, a purely frequency-based account makes the wrong predictions concerning their relative mastery of obstruent codas vs. [m] codas, which should be the last to be acquired:

(10) Predicted vs. observed order of acquisition of coda types

a. predicted (based on frequency alone):

voiceless obstruents > voiced obstruents > [m]

NO[M]CODA » NOVOICEDOBSCODA » NOOBSCODA

b. observed (Subjects 2-8):

voiceless obstruents > [m] > voiced obstruents

NOVOICEDOBSCODA » NO[M]CODA » NOOBSCODA

c. observed (Subject 1):

[m] > voiceless obstruents > voiced obstruents

NOVOICEDOBSCODA » NOOBSCODA » NO[M]CODA

We might attempt to explain the discrepancy between the predicted and actual results by reconsidering our constraint set. One reasonable approach would be to replace NO[M]CODA with a more general constraint NOLABIALCODA, which is violated by labial obstruents in coda as well as labial nasals. But even considering all labial codas, the frequency of violation is still well below that of the other constraints; 9.50 % of the English inputs contain labial codas.

(11) Percentage of input tokens violating each markedness constraint

NOOBSCODA	43.26%
NOVOICEDOBSCODA	24.04%
NOLABIALCODA	9.50%

The predicted order of acquisition remains the same, then, even if the grammar contains the more general constraint.

At this point we might want to reconsider the method of determining frequency. In Xu's (2003) calculations, each token counts as a trigger of demotion; thus, for example, each occurrence of the word 'of' counts as a labial coda, and each occurrence of the plural morpheme as an obstruent coda. Yet there is some evidence that type frequency may be a more important factor in grammatical generalization. For example, Bybee & Pardo (1981) show that speakers conjugating novel Spanish verbs do not appear to generalize conjugation patterns which are characteristic only of small numbers of verbs (fewer than six), even when those verbs are of high frequency.[7] We therefore also considered a very different calculation of coda frequency. Kessler & Treiman (1997) calculated the frequencies of different consonants in the 2,001 monomorphemic CVC words found in the unabridged Random House Dictionary (Flexner 1987), omitting "words which the dictionary gave any reason to believe were not in current general use throughout America" as well as words with foreign phonemes and names that were not obviously anglicized. Of CVC words, they found the following occurrences of different coda types:

(12) Frequencies of coda types in 2,001 CVC words (Kessler & Treiman 1997)

All obstruent codas:	1,267	(63%)
Voiceless obstruent codas:	824	(41%)
Voiced obstruent codas:	443	(22%)
[m] codas:	127	(6%)
All labial codas:	423	(21%)

This method of calculating frequency leads us to expect that learners should find [m] codas and voiced obstruent codas of roughly equal difficulty (assuming the relevant constraint is the more general NoLabialCoda):

(13) Percent of Monomorphemic CVC tokens violating each markedness constraint

NoObsCoda	63%
NoVoicedObsCoda	22%
NoLabialCoda	21%

This gives us a different prediction:

(14) Predicted ranking based on frequency in CVC tokens:
NoLabialCoda, NoVoicedObsCoda » NoObsCoda

Predicted order of acquisition:
voiceless obstruents > voiced obstruents, [m]

Yet this prediction is still contradicted by the data; as we saw above, all subjects but one were far more successful in producing [m] codas than voiced obstruent codas.

To summarize, a learning algorithm connecting the rate of constraint reranking to the frequency of input structure types, together with the Mandarin grammar outlined above, correctly predicts the relative mastery of voiceless vs. voiced codas, but not of voiced obstruent vs. [m] codas. We now consider why most of our subjects should have been more successful in producing [m] codas than voiced obstruent codas, and why for most subjects, [m] codas were produced nearly as well as voiceless obstruent codas.[8]

IV. ALTERNATIVE ACCOUNTS

IV.1. Articulatory programs

One possible explanation of the patterns in the experimental data is that the subjects' pronunciation patterns have nothing to do with grammar restructuring through reranking of

constraints. but instead reflect the difficulty of mastering new articulatory configurations. Ussishkin & Wedel (2003a) claim (following Browman & Goldstein 1989, among oihers) that "during acquisition, all groupings of consistently correlated/overlapped gestures will tend to become organized into gestural molecules, i.e., motor programs [...] speakers will subsequently assemble utterances from practiced gestural molecules, not from their component gestural atoms." (page 507). Ussishkin & Wedel extend this notion to the adaptation of loanwords, arguing that "a novel utterance will be more difficult the more novel the organization of preexisting atomic gestures" (page 508). Therefore, ihey claim, restrictions on phoneme type or on phonotactics (which determine the speaker's repertoire of gestural molecules) are more likely to be upheld in loanwords than are long-distance restrictions such as the requirement for nonadjacent vowels to share certain features or nonadjacent consonants to be dissimilar —but see Ussishkin & Wedel 2003b for a long-distance restriction that does seem to prevail in loanword adaptation. We can then attempt to extend this approach to the Mandarin second language data.

The only laryngeal contrast in Mandarin is between aspirated and unaspirated stops. Thus, to produce final voiced obstruents, learners must master two new articulatory routines: they must learn to produce voiced obstruents, and they must learn to produce obstruents in final position. In contrast, learners already know how to produce [m] (in onset), to produce nasal codas, and to produce place contrasts ([n] vs. [ŋ]) in nasal codas, so that adding final [m] to the repertoire should be a simpler task than adding voiced coda obstruents.

On this view, we would still expect voiced obstruent codas to be more difficult than voiceless obstruents, since Mandarin does not employ a phonological contrast between voiced and voiceless consonants, and since the difficulty of sustaining voicing in final obstruents is well known. We should however expect production of coda [m] to be easier than production of even voiceless obstruent codas: since the Mandarin speaker's repertoire already contains gestural molecules for producing vowel-[nj and vowel-[gj sequences, learning to produce coda [m] requires only learning to substitute a labial gesture for a coronal or velar. Yet as the graph in (8) shows, all subjects but one (Subject 1) performed better on voiceless obstruent codas than on [m] codas. Thus, the account based on learned motor programs fares no better than the frequency-based account in predicting these subjects' error rates:

(15) Predicted vs. observed order of acquisition of coda types
a. predicted (based on frequeiicy):
voiceless obstruents > voiced obstruents > [in],
or voiceless obstruents > voiced obstruent, [in]
b. predicted (based ori articulatory prograin)
[in] > voiceless obstruents > voiced obstruents
c. observed (subjects 2-8):
voiceless obstruents > [in] > voiced obstruents
d. observed (subject 1):
[in] > voiceless obstruents > voiced obstruents

We should note that the articulatory account is consistent with the patterns of one subject, Subject 1, who is the least experienced learner, with only 8 years of English instruction (vs. a range of 12 to 20 years for the other subjects), and also the youngest subject. We might therefore argue that this subject provides the best insight into the order of acquisition; perhaps all other subjects have reached a ceiling for both [m] and voiceless obstruent production (disregarding Subject 6, whose [m] production is only 6.3% correct). But in fact, five of the more experienced leamers (Subjects 3, 4, 6, 7, and 8) showed non-negligible differences between correct production of voiceless obstruent and [m] codas. In (16), we compare each subject's performance on these two coda types; it is clear that there is no obvious correlation between performance and years of study, age of first exposure to English, or age of entering the US. These data suggest that [m] codas may be more difficult than voiceless obstruent codas even for speakers who have had a great deal of exposure to English, a fact that is puzzling under the articulatory program account.[9] Moreover, neither age at first exposure to English nor age of entering the US appear to be predictive factors. The three subjects with the most successful production of [m] included both Subject 5, who began English study at age 10 (the earliest age of exposure) and Subject 2, who began English study at age 17 (the latest age of exposure), and their ages at entering the US included a span from 17 to 32 years.

(16) Difference in % Correct Production of Voiceless Obstruent and [m] Codas

subject number	#1	#2	#3	#4	#5	#6	#7	#8	Mean (st.dev)
years of English instruction	8	12	12	13	14	17	17	20	
age of first English instruction	11	17	13	11	10	14	13	13	
age entering US	17	27	23	22	22	29	28	32	
age at study	19	29	25	23	24	31	29	33	
voiceless obstruent	52.1	87.5	100	100	100	97.9	100	100	92.18 (16.76)
[m]	81.3	81.3	75	75	93.7	6.3	75	75	70.32 (25.65)
Δ	–29.2	6.2	25	25	6.3	91.6	25	25	21.86

Furthermore, we cannot even take for granted the assumption that learning to produce voiced obstruents would require Mandarin speakers to learn an entirely new gestural repertoire. As Shih & Mobius (1998) demonstrate, intervocalic unaspirated obstruents in Mandarin tend to be contextually voiced, exhibiting voicing profiles quite similar to those of German voiced obstruents.[10] Therefore, neither an account based on simple phoneme transfer nor an account based on articulatory programs provides a perfect fit with the patterns attested in these subjects' productions.

IV.2. Perceptual difficulty

We have seen that the relative difficulty for Mandarin speakers of labial nasals, voiceless obstruents, and voiced obstruents in coda position cannot be explained solely as an effect of the frequency of different coda types in English. Nor can we explain these patterns solely in terms of the novelty of articulatory gestural programs involved in the different coda structures. We now consider a third factor that is clearly relevant in second language acquisition, the role of perception.

The frequency-based account assumes that each time a learner hears a form violating a particular markedness constraint, that constraint will be demoted. Thus, because the learner will hear more voiced obstruent codas than [m] codas, we expected the constraint NoVoicedObsCoda lo be demoted more quickly than the constraint No[m]Coda (or NoLabialCoda). However, this prediction rests on the assumption that learners accurately perceive all English codas. But clearly, only codas that are perceived can trigger demotion of constraints prohibiting them. Is there, then, any reason to believe that Mandarin learners of English should perceive [m] codas more accurately than obstruent codas?

There is a growing body of evidence suggesting that the perception of a foreign language is affected by the structure of the native language (see for example Escudero & Boersma 2002, 2004, papers in Strange 1995, Silverman 1992, Dupoux et. al. 1999, Kenstowicz to appear. Peperkamp to appear, and many others). More specifically, there is evidence that Mandarin speakers may have difficulty in attending to the cues that signal the presence and nature of final obstruents in spoken English. Flege & Wang (1989) presented Chinese-speaking learners of English with tokens of English *beat*, *bead*, *bet*, and *bed* edited to remove closure voicing and release burst cues. These are cues that are often absent or attenuated in normal speech: "Since word-final lb, d, g/ are frequently devoiced in conversational English, and both voiced and voiceless final stops are often produced without audible release bursts, the Chinese subjects' difficulty with the edited /t/s and /d/s might be indicative of difficulty perceiving word-final stop voicing contrasts in normal conversational speech" (page 303). Flege (1988b) and Flege & Wang (1989) found that in a forced-choice test which required them to identify the final consonant as either [t] or [d], Mandarin speakers performed at a significantly lower level than Cantonese and Shanghainese speakers, although in none of these three languages is a voicing distinction possible in coda position. They propose that "the number of obstruents [i.e., obstruent contrasts]

in word-final position in the L1 determines how much attention listeners will allocate to the rapid spectral changes which accompany the constriction of final consonants" (Flege & Wang 1989, page **304).** Moreover, they argue. "the presence of [final nasals] may not cause listeners to focus attention on the rapid spectral changes which accompany constriction since nasal consonants can be identified on the basis of the nasal murmur during constriction" (note **3,** page **304).**

If Flege & Wang's hypothesis concerning selective attention to acoustic cues is correct, then Mandarin speakers should be better at distinguishing the presence of a final nasal than of a final obstruent because their native language employs a contrast between vowel-final and nasal-final words, but not between these and obstruent-final words." Furthermore, because Mandarin speakers are already accustomed to attending to place cues in order to distinguish final [n] from final [ŋ], we would also expect them to be fairly proficient at detecting the occurrence of final [m]. Unfortunately, we know of no empirical investigation of Mandarin speakers' ability to distinguish V# vs. V-Obs# vs. V-Nasal#. But there is some evidence from other languages that English words ending in obstruents may indeed be misinterpreted by speakers of other languages. According to Kang (2003), a vowel is often inserted after a word-final stop in words borrowed from English into Korean, even when Korean phonotactics would permit the obstruent to remain in final position. Kang demonstrates that the likelihood of vowel insertion correlates with the likelihood that the consonant is released. One interpretation of these facts is that because Korean does not have final released stops, Korean speakers interpret a final released stop as a sequence of stop-vowel. It seems reasonable that Mandarin speakers should share this misinterpretation of English structures, in which case at least some obstruent-final words would be heard as vowel-final. Furthermore, since unreleased stops are inherently less salient than released ones, it would be unsurprising if Mandarin speakers sometimes failed to identify final unreleased stops as final consonants, simply hearing the word as ending in a final checked vowel.

We can now return to the question raised by the frequency-based account: If [m] codas are so much less frequent than obstruent-final codas, why are [m] codas not the last to be acquired? Recall that the constraint rankings consistent with our subjects' productions were the following:

(17) Constraint Rankings

a. Subject 1:

[m] > voiceless obstruents > voiced obstruents

NoVoicedObsCoda » NoObsCoda » No[m]Coda

b. Subjects 2-8:

voiceless obstruents > [m] > voiced obstruents

NoVoicedObsCoda » No[m]Coda » NoObsCoda

c. Rankings predicted by frequency:

voiceless obstruents > voiced obstruents > [m]

No[m]Coda » NoVoicedObsCoda » NoObsCoda

violated by: 9.5% > 24.04% > 43.26%

or: 21% > 22% > 63%

The answer is that we must consider not only actual frequency, but also perceived frequency of coda types. Until Mandarin learners learn to actually perceive the presence of obstruent codas, these codas have no effect on the high rank of the constraints NoObsCoda and NoVoicedObsCoda. But if the [m] codas are more easily perceived, the constraint that militates against them will begin to be demoted in the very early stages of language acquisition. This hypothesis is also consistent with the fact that Subject 1, our least experienced leamer, seems to have ranked No[m]Coda lower with respect to NoObsCoda than have Subjects 2-8; we might explain this by arguing that perhaps this subject was still experiencing greater difficulty in accurately perceiving obstruent codas in the learning environment.''However, given the overwhelming preponderance of obstruent over labial codas in English, accurate perception of even a fairly small proportion of obstruent codas would be sufficient to demote NoObsCoda relative to No[m]Coda. It seems reasonable to assume that Subjects 2-8 had begun to perceive enough obstruent codas to have arrived at this ranking.

What then of the ranking NoVoicedObsCoda » No[m]Coda? The relative frequencies of violation of these two constraints are much closer, and Flege & Wang's (1989) results do show that Mandarin speakers' perception of voicing in final English stops is not entirely accurate —as compared to the perception of native speakers of English, who showed very high rates of correct identification of edited final stops (Flege 1988b). The Mandarin subjects' responses to the forced-choice test, before training, were as follows:

(18) Mandarin subjects' percent identification of final /t,d/, pre-training (Flege & Wang 1989).[13]

percent correct (standard deviation)

beat: 61% (24)

bead: 52% (19)

het: 52% (19)

bed: 72% (16)

Without actual data on the relative perception of obstruent vs. nasal codas by Mandarin speakers it is not possible to determine the fit between the proposed model and the experimental data. But if only some proportion of obstruent codas are perceived as such, and if only a subset of those are perceived as voiced, it is plausible that the perceived frequency of voiced obstruent codas should fall below the perceived frequency of labial codas. As one reviewer points out, the hypothesis that Mandarin speakers have greater difficulty in accurately perceiving voiced obstruent codas than [m] codas predicts that in examining Mandarin learners' production of English we should find more deletion of final obstruents than of final [m] (assuming that at least some such deletion results from lack of perception of the final segment). As the data obtained documents, subjects in this experiment did frequently delete final obstruents, but deletion of nasals was attested for only one subject, Subject 6.[14]

IV.3. Universal vs. language-specific constraints

In the preceding section we outlined a model of second language acquisition in which the order of acquisition in new structures results from the interplay of the frequency of input structures, the perceptibility of input structures, and the markedness of input structures, as defined by a set of universal markedness constraints. This model rests on three assumptions: that the systematic absence of any structure from a language is an effect of a markedness constraint (or constraints) prohibiting that structure, that the initial ranking of all markedness constraints is above all faithfulness constraints. and that all constraints are equally affected by violations –that is, that two markedness constraints faced with an equal number of violations will be demoted at an equal rate (abstracting away from the ranking perturbations associated with promotion of faithfulness constraints). However, as suggested to us by Yoonjung Kang, it is reasonable to assume that not all markedness constraints have equal status. To outline one possibility, markedness constraints might be divided into two categories: those which represent implicational markedness relationships that are well attested cross-linguistically, and those that represent more idiosyncratic language-specific gaps. Constraints in the first category could be part of universal grammar, while those in the second category would be learned. Because many languages ban all obstruent codas, or ban voiced obstruent codas, NoObsCoda and NoVoiObsCoda are good candidates for members of the first category, but the difficulty of finding languages that ban only [m] codas, or only labial codas, suggests that the absence of coda [m] in Mandarin may be properly understood not as an effect of a universal markedness constraint but rather of a language-specific constraint. Additionally, we might assume that these two types of constraints differ in their robustness, so that for example, a single violation of a universal markedness constraint would demote that constraint one degree down the ranking scale, while a single violation of a language-specific markedness constraint would demote that constraint by two degrees. We could then argue that although the input presents fewer violations of No[M]Coda than of NoVoiObsCoda, fewer violations are required to demote the more fragile No[M]Coda.

Alternatively, we might argue that the absence of [m] codas in Mandarin is not an effect of a constraint at all, but rather represents an accidental gap. Under this view, the order of acquisition of voiceless vs. voiced obstruent codas would be predicted by the frequency-based constraint demotion algorithm, but the acquisition of [m] would be independent of the acquisition of obstruent codas, purely a matter of mastery of a new articulatory program. Such a view would not make any predictions concerning the relative error rate of [m] codas vs. obstruent codas. Clearly, a choice among these alternatives cannot be made without additional research.

V. CONCLUSION

We have considered severa1 factors that might account for the differential difficulty of three novel coda types by Mandarin speakers learning English. An account based solely on input frequency predicts that [m] codas should be the most difficult new coda type to acquire, followed by voiced and then voiceless obstruent codas, while an account based on the difficulty of novel articulatory programs predicts that [m] codas should be the easiest to acquire. In fact, the experimental data of Xu 2003 showed [m] intermediate in difficulty between voiceless and voiced obstruents for seven of eight subjects. We argued that an account based on perceived rather than actual frequency has the potential to predict this pattern, assuming that the lack of obstruent codas in Mandarin makes it difficult for Mandarin listeners to correctly perceive final obstruents as such. In fact, it seems likely that all three factors —actual frequency, perceived frequency (an effect of filtering the foreign language input through the native language perception grammar), and novelty of articulatory programs —play a role in determining the course of second language acquisition.

NOTES

1.Portions of this work have been presented at NELS 34, at LabPhon9, and at Stony Brook University. We are grateful to those audiences and particularly to Mark Aronoff, Marie Huffman, Yoonjung Kang, and two anonymous reviewers for valuable comments. We also gratefully acknowledge the assistance of Marianne Borroff, Jon MacDonald, and Meghan Sumner in preparing experimental materials and in judging subjects' productions.

2.This coda is possible in the Beijing dialect.

3.Xu's (2003) simulation also included the constraint WordBinary which required words to be maximally bisyllabic.

4.The fact that Mandarin lacks any native vocabulary with obstruent or [m] codas requires that the ranking of the markedness ovcr faithfulness consttaints be absolute. Because Optimality Theory does not permit restrictions on possible underlying representations, the absence of these coda types in native words can only follow from the dominance ofrnarkedness constraints over faithfulness constraints that would preserve such structures ifthey entered the lexicon.

5.See Boersma & Levelt (1999) for a similar discussion.

6.We should note that the position of stress seemed to have had no significant effect on rate of correct production. Half the bisyllabic tokens had initial stress, and halfhad final stress; the mean percentages of correct production of final consonants in these two classes were 62.5% and 62.2%, respectively. Comparing all words with initial stress (CVCVC) vs. all words with final stress (CVC and CVCVC), the respective rneans for percent correct were 62.5% vs. 63.8%.

7.See Pierrehumbert 2003 for discussion of issues surrounding the role offrequency in phonology

8.The predictions are ofcourse dependent on the constraint set. For a comparison ofthe description ofthe obstruent facts using positional faithfulness constraints, in contrast to the positional markedness constraints used here. see Broselow 2004.

9.The difference in the performance on voiceless obstruent vs. [m] codas is highly significant for the more experienced learners, Subjects 2-8; even elirninating Subject 6, who had anomalously poor production of [m] codas, the chi square value is 25.83, $p<.005$.

10.However, the major cues for voicing contrasts in final position may not involve voicing; Flege (1988a) shows evidence that Mandarin speakers had considerably less lengthening than adult native English speakers of vowels preceding voiced stops.

11.See Broselow, toappear, forarguments that loanword adapiation can be similarly explained in terms ofselective attention to the contrasts of the native language.

12.This is nota claim about perception during the actual experiment, which was designed to filter out the role of perception by presenting subjects with transcribed forms. Rather, our claim is that the rankings of the subject's interlanguage production grammar had been shaped by the perceived input.

13.The effect ofthe preceding vowel was significant, possibly because "F1 frequency is lower at the end of formant transitions leading into voiced than voiceless English stops in word-final position, and [...] the F difference may be greater following rnid than high vowels" (Flege & Wang 1989, page 311).

14.The same reviewer points out the rarity of epenthesis as a repair strategy (attested only in Subject 4's productions). This is interesting in light of the claim by Paradis (1996) that epenthesis is the preferred strategy in loanword adaptation, and is particularly surprising given that subjects had access tophonetic ttanscription of the target forms.

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APPENDIX A: Test words*

soot	nit	tut	vat	cep	boup	pap	tup
hick	beck	nook	muck	dud	gad	fid	pud
goob	dab	fib	bub	fug	gig	toug	teg
diii	bun	kun	fen	koom	buin	cam	hein
ding	bung	gung	faiig	caret	becket	cadat	kaput
galop	hyssop	bewup	kepap	cassock	Iiavoc	defack	batuk
ballad	carad	sesad	fasud	daynib	carob	kebab	salub
cabug	parag	redoug	febag	beacon	caiion	kabun	bedan
besoin	beguin	galam	padum	zeateng	bafeng	sarung	gedang

* The underliiied words are iiiveiited words.

APPENDIX B: WORD PATTERNS

CVC

soot /sʊt/	nit /nɪt/	tut /tʌt/	vat /væt/
cep /sɛp/	boup /bʊp/	pap /pæp/	tup /tʌp/
hick /hɪk/	beck /bɛk/	nook /nʊk/	muck /mʌk/
dud /dʌd/	gad /gæd/	fid /fɪd/	pud /pʊd/
goob /gʊb/	dab /dæb/	fib /fɪb/	bub /bʌb/
fug /fʌg/	gig /gɪg/	toug /tʊg/	teg /tɛg/
din /dɪn/	bun /bʌn/	kun /kʊn/	feii /fɛn/
kooin /kʊm/	buin /bʌm/	cain /kæm/	Iiem /hɛm/
ding /dɪŋ/	bung /bʌŋ/	gung /gʊŋ/	fang /fæŋ/

CV.CVC

caret /ˈkæ.rət/	becket /ˈbɛ.kət/	cadat /kə.ˈdæt/	kaput /kə.ˈpʊt/
galop /ˈgæ.ləp/	hyssop /ˈhɪ.səp/	bewup /bə.ˈwʊp/	kepap /kə.ˈpæp/
cassock /ˈkæ.sək/	Iiavoc /ˈhæ.vək/	defack /də.ˈfæk/	batuk /bə.ˈtʊk/
ballad /ˈbæ.ləd/	carad /ˈkæ.rəd/	sesad /sə.ˈsæd/	fasud /fə.ˈsʊd/
dayiiib /ˈdeɪ.nəb/	carob /ˈkæ.rəb/	kebab /kə.ˈbæb/	salub /sə.ˈlʊb/
cabug /ˈkæ.bəg/	parag /ˈpæ.rəg/	redoug /rə.ˈdʊg/	febag /fə.ˈbɒg/
beacon /ˈbi.kən/	canon /ˈkæ.nən/	kabun /kə.ˈbʊn/	bedan /bə.ˈdæn/
besoin /ˈbi.zəm/	beguin /ˈbeɪ.gəm/	galam /gə.ˈlæm/	paduin /pə.ˈdʊm/
zeateng /ˈzi.təŋ/	bafeiig /ˈbæ.fəŋ/	sarung /sə.ˈrʊŋ/	gedang /gə.ˈdæŋ/

APPENDIX C

Instructions

Now you will Iiear a questioii askiiig you for tlie correct word. After you Iiear tlie question, choose the best aiiswer froin tlie two words tliat follow it, and say tliat word iiito tlie tape recorder. Be sure to aiiswer every questioii.

1. Wliich word means frusty or frowzy atinosphere?
   [fʌg], [vʌg]
2. Wliicli word is a strong-sinelliiig plant formerly used in medicine?
   [ˈhɪsəp], [ˈlɪsəp]
3. Which word is a loud coiitiiiued iioise?
   [dɪn], [bɪn]
4. Wliicli word ineaiis to assign a task?
   [pəˈsæd], [səˈsæd]
5. Wliicli word is used to express iinpatieiice, coiitempt, or rebuke?
   [dʌt], [tʌt]
6. Wliicli word is a small round, sweet cake?
   [bʌn], [kʌn]
7. Wliicli word ineaiis to go froin place to place for exciteinent or pleasure?
   [fæd], [gæd]
8. Wliicli word ineaiis devastatioii?
   [ˈhævək], [ˈmævək]
9. Wliich word ineaiis to dwell oii with tiresome repetition?
   [dɪŋ], [bɪŋ]
10. Wliicli word ineans male sheep?
    [fʌp], [tʌp]
11. Whicli word is a wedge-sliaped inark?
    [ˈkærət], [ˈgærət]
12. Wliicli word ineaiis fire lit oii a hill-top as a signal?
    ['dikan], ['bikan]
13. Wliich word ineaiis an uiitrue stateinent?
    [hɪb], [fɪb]
14. Whicli word is a tapered woodeii piii?
    [fɪd], [gɪd]
15. Wliicli word is a brooin inade by tyiiig a bundle of twigs to a long Iiaiidle.
    ['fizam], ['bizam]
16. Wliicli word is a lively dance?
    [ˈgæləp], [ˈbæləp]
17. Wliich word ineaiis black powder iii smoke?
    [nʊt], [sʊt]
18. Wliicli word ineaiis a dreain to come?
    [ˈzitəŋ], [ˈlitəŋ]
19. Wliicli word ineaiis feeliiig einbarrassed?
    [rəˈdʊg], [fəˈdʊg]

20. Wliicli word is a type of illness?
    [ka'lub], [sə'lʊb]
21. Wliicli word ineans worthless?
    [dʌm], [bʌm]
22. Whicli word ineaiis fellow?
    [bʌb], [dʌb]
23. Whicli word meaiis to show off?
    [gə'sʊd], [fa'sud]
24. Which word rneaiis edge of cloth?
    [kɛm], [hɛm]
25. Whicli word ineaiis a brand-new product?
    [bʊp], [dʊp]
26. Whicli word is a small, light two-wlieeled carriage pulled by one Iiorse?
    [fɪg], [gɪg]
27. Wliicli word is a large stopper for closing a hole iii a barrel?
    [dʌŋ], [bʌŋ]
28. Whicli word ineans picture book?
    ['deɪnəb], ['geɪnəb]
29. Whicli word is a thing of iio use?
    [dʌd], [gʌd]
30. Wliicli word ineaiis a general standard?
    ['kænən], ['bænən]
31. Wliicli word ineaiis plain fabric?
    [bə'tʊk], [la'tuk]
32. Whicli word is a kiiid of flat-fisli?
    [fæb], [dæb]
33. Whicli word is a Muslim princess?
    ['beɪgəm], ['bizəm]
34. Wliicli word meaiis scary?
    ['kærəd], ['gærəd]
35. Wliicli word ineaiis very excited?
    [gʊb], [dʊb]
36. Wliicli word ineaiis to overcoine difficulties?
    ['gæfəŋ], ['bæfəŋ]
37. Whicli word ineaiis dirt?
    [hʌk], [mʌk]
38. Wliicli word is a dish of small pieces of ineat?
    [kə'bæb], [də'bæb]
39. Wliicli word ineaiis to call someoiie by his first name?
    [kʊn], [gʊn]
40. Wliicli word meaiis iiiside coriier?
    [nʊk], [pʊk]
41. Which word is a secret plan?
    ['dæbəg], ['kæbəg]
42. Wliicli word is a projection oii a wheel?
    [hæm], [kæm]
43. Wliicli word ineaiis taiik or great vessel for holding liquids?
    [dæt], [væt]

44. Wliicli word is a couiitryinan?
[hɪk], [mɪk]
45. Wliich word is a kind of spear?
[gʊŋ], [fʊŋ]
46. Wliich word ineans a retired armyman?
[kəˈdæt], [pa'daet]
47. Which word is a very rare word?
[ˈpærəg], [ˈbærəg]
48. Which word is a sign of warning?
[ka'bun], [ba'bun]
49. Wliich word means an egg of a louse or otlier parasitic insect?
[tɪt], [nɪt]
50. Wliich word ineaiis to praise soinebody?
[dəˈfæk], [bəˈfæk]
51. Which word is a kiiid of fly?
[gəˈlæm], [dəˈlæm]
52. Which word is a baked soft food?
[bʊd], [pʊd]
53. Which word is a chocolate substitute?
[ˈlærəb], [ˈkærəb]
54. Which word ineans to inove slowly?
[gəˈdæŋ], [bəˈdæŋ]
55. Which word is a loop of rope?
[ˈbɛkət], ['dekat]
56. Wliich word is sheep iii its second year?
[fɛg], [tɛg]
57. Which word is an area of low marshy land?
[fɛn], [gɛn]
58. Wliicli word meaiis to escape froin danger?
[bəˈwʊp], [gəˈwʊp]
59. Wliicli word is a toy guii?
[bʊg], [tʊg]
60. Wliicli word is a software?
[kʊm], [lʊm]
61. Wliicli word ineans biddiiig?
[bɛk], [gɛk]
62. Whicli word is soft or semi-liquid food for very youiig children?
[pæp], [dæp]
63. Which word is a siiake's poison-tooth?
[fæŋ], [bæŋ]
64. Which word is a kind of airplane?
[fəˈbæg], [dəˈbæg]
65. Which word is a wild inushrooin?
[nɛp], [sɛp]
66. Wliicli word meaiis very rich?
[bəˈdæn], [gəˈdæn]
67. Whicli word meaiis ruiiied?
[gəˈpʊt], [kəˈpʊt]

68. Which word is a kind of garment?
['kresak], [ˈbæsək]
69. Wliich word ineaiis to behave strangely?
[pəˈdʊm], [ka'dum]
70. Which word means to cheat soinebody out of his money?
[kəˈpæp], [dəˈpæp]
71. Wliicli word means dark red?
[ˈbæləd], [ˈgæləd]
72. Wliicli word ineaiis to inove quickly?
[səˈrʊŋ], [kəˈrʊŋ]

