

RESEARCH ON SPOKEN LANGUAGE PROCESSING
Progress Report No. 22 (1998)
Indiana University

**Recognition of Spoken Words by Native and Non-native Listeners:
Talker-, Listener- and Item-related Factors¹**

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¹ This research was supported by NIH-NIDCD Training Grant DC-00012 and by NIH-NIDCD Research Grant DC-00111 to Indiana University. Earlier versions of this work were presented in the Fall of 1997 at the 134th meeting of the Acoustical Society of America in San Diego, CA (2-6 December, 1997), and at the International Symposium on Speech Perception by Non-Native Listeners in Boston, MA (19-21 November, 1997). We are grateful to Gina Torretta for data collection and processing, and to Luis Hernandez for technical support. We thank Paul Luce for suggesting this analysis to us.

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Recognition of Spoken Words by Native and Non-native Listeners: Talker-, Listener- and Item-related Factors

Abstract. In order to gain insight into the interplay between the talker-, listener-, and item-related factors that influence speech perception, we developed a large multi-talker database of digitally recorded spoken words that were then submitted to intelligibility tests with multiple listeners. Ten talkers produced two lists of words at three speaking rates. One list contained lexically “easy” words (words with few phonetically similar sounding “neighbors” with which they could be confused), and the other list contained lexically “hard” words (words with many phonetically similar sounding “neighbors”). An analysis of the intelligibility data obtained with native speakers of English (Experiment 1) showed a strong effect of lexical similarity. Easy words had higher intelligibility scores than hard words. We also found a strong effect of speaking rate whereby slow and medium rate words had higher intelligibility scores than fast rate words. Finally, we also observed a complex relationship between the various stimulus factors whereby the perceptual difficulties imposed by one factor, such as a hard word spoken at a fast rate, could be overcome by the advantage gained through the listener’s experience and familiarity with the speech of a particular talker. In Experiment 2, we extended our investigation to another listener population, namely, non-native listeners. Results showed that the ability to take advantage of consistent surface phonetic information, such as a consistent talker across items, is a perceptual skill that transfers easily from first to second language perception. However, non-native listeners had particular difficulty with lexically hard words even when familiarity with the items was controlled, suggesting that non-native word recognition may be compromised when fine phonetic discrimination at the segmental level is required. Taken together, the results of this study provide insight into the signal-dependent and signal-independent factors that influence spoken language processing in native and non-native listeners.

Introduction

Speech perception and spoken word recognition accuracy depend on a wide range of talker-, listener- and utterance-related characteristics, all of which can vary across communicative situations. A large and continuously growing body of work has provided us with important new information regarding the way in which talkers modify their speech production and articulation depending on a wide range of linguistic and paralinguistic factors. For example, Lindblom (1990) showed how speakers vary their output along a continuum of hyper- and hypo-speech, using hyper-speech to assist a listener under “difficult” listening conditions, and hypo-speech when the talker believes less articulatory precision can be tolerated by the listener. A similar idea has been investigated over the past decade or so in a series of studies that examined the acoustic-phonetic factors that differentiate a conversational style of speech from a “clear” style of speech, such as one might use when addressing a person with a hearing loss (Picheny, Durlach, and Braida 1985, 1986, 1989; Uchanski et al. 1996). Similarly, under the “Lombard effect,” talkers increase their vocal effort when talking in a noisy environment (Hanley and Steer, 1949; Draegert, 1951; Lane and Tranel, 1971), and adults adopt a hyper-articulated style of speech when addressing infants (Fernald and Simon, 1984; Fernald et al., 1989; Grieser and Kuhl, 1988; Kuhl et al. 1997). These studies, and many others, have provided a great deal of new information about the way in which individual talkers modify their articulatory patterns to accommodate situational demands. However, aside from establishing that the “clear” speech style does indeed provide an intelligibility advantage over

“conversational” speech (Picheny, Durlach and Braida, 1985), considerably less attention has been paid to the direct perceptual consequences, from the listener’s point of view, of different styles of speech (see also Summers et al., 1988; Lively et al., 1993). Important questions that remain to be answered are: (1) Which of the “clear” speech transformations are most effective in aiding speech communication? And (2), how do listeners tune their performance according to communicative and situational demands? In order to develop a complete understanding of the interplay between the talker-, listener-, and item-related factors that influence speech production and perception, we need to look at how the speech signal varies across a range of conditions, as well as the effects of these sources of variation on listener performance.

With this overall goal in mind, recent work in our laboratory has focused on some of the factors that contribute to the observed variability in speech perception at the word and sentence levels from the listener’s point of view. To date, several factors have been shown to directly influence overall speech intelligibility by native listeners of American English. First, the degree of variability in the stimulus materials has been shown to have a major impact on the listener’s speech recognition accuracy. For example, word recognition accuracies decrease and response times increase when listeners are presented with spoken word lists that incorporate a high degree of stimulus variability due to the presence of multiple talkers and multiple speaking rates, relative to spoken word lists in which such stimulus variability is minimized (Mullennix et al., 1989; Sommers et al., 1994). Second, familiarity on the part of the listener with the talker’s voice and articulatory characteristics enhances word recognition accuracy under difficult listening conditions. For example, Nygaard, Sommers and Pisoni (1994) showed recently that listeners were more accurate at identifying novel words in noise when the words were spoken by a familiar talker than when the same words were spoken by a novel talker. Third, the lexical characteristics of the particular words in a stimulus set exert a strong influence on overall intelligibility. Several studies have shown that lexically “easy” words (i.e., words with few phonetically similar “neighbors” with which they could be confused) are recognized better than lexically “hard” words (i.e., highly confusable words with many phonetically similar neighbors) (Pisoni et al., 1985; Luce, 1986; Luce et al., 1990; Luce and Pisoni, 1998). Finally, in a first attempt at identifying the talker-specific acoustic-phonetic characteristics that correlate with inter-talker intelligibility differences, Bradlow et al. (1996) showed that talkers who exhibited a high degree of “articulatory precision” in their speech generally had higher overall speech intelligibility scores than talkers who tended to produce more “reduced” speech (see also Wright, 1997). Taken together, these recent studies demonstrate that a range of talker-, listener- and item-related factors combine to produce the observed variability in overall speech intelligibility.

The present study continues this line of research by investigating the separate and combined effects of various talker-, listener-, and item-related characteristics on recognition of isolated words by both native and non-native listeners. In Experiment 1, we developed a large database of digital speech recordings that could be used to assess the effects of speaking rate, lexical discrimination, and listener-talker adaptation on isolated word intelligibility. By directly examining the separate and combined effects of these characteristics on native-language speech intelligibility, we hoped to gain insight into perceptual processes that underlie native language word recognition. Specifically, we wanted to investigate the separate and combined effects of “signal-dependent” factors, such as speaking rate, and “signal-independent” factors, such as knowledge of the sound-based structure of the lexicon (Lindblom, 1990). Furthermore, the availability of this carefully constructed, multi-talker, multi-listener database provided us with a set of digital speech recordings along with normed intelligibility scores that could then be used in experiments that directly investigate spoken word recognition in a variety of “special” populations like non-native listeners or listeners with hearing impairments. Accordingly, in Experiment 2 we used the same materials as in Experiment 1 to investigate stimulus variability and spoken word recognition by non-native listeners. We wanted to see how non-native listeners cope with stimulus variability, and which demographic and linguistic variables correlate with non-native speech intelligibility.

The overall goal of this pair of experiments was to describe in detail, and ultimately to provide a principled account of the relations between the various talker-, listener- and item-related factors that influence spoken word recognition by both native and non-native listeners. While this was primarily an exploratory study, we believe that this type of fundamental knowledge about the way in which listeners compensate for multiple sources of variability provides insight into the perceptual mechanisms that underlie spoken language processing. Our approach to the study of speech variability stems from a basic view of speech communication as a highly adaptive process on the parts of both the talker and the listener. We believe that the use of large multi-talker multi-listener speech databases is essential for gaining a deeper understanding of the stimulus variability that is inherent in real-world speech production and perception.

EXPERIMENT 1

Method

The “Easy” and “Hard” Word Lists

An “easy” list and a “hard” list of words (75 items each) were constructed such that the two lists differed in terms of three lexical characteristics (Pisoni et al., 1985; Luce, 1986; Luce et al., 1990; Luce and Pisoni, 1998). First, using the word frequency counts provided by the Brown Corpus of printed text (Kucera and Frances, 1967), the words were selected such that the mean word frequency of the easy list was significantly higher than that of the hard list (309.7 vs. 12.2. per million). Second, using an on-line version of Webster’s Pocket Dictionary (20,000 entries) in conjunction with a custom-designed lexical search program, words were selected such that the neighborhood density (the number of phonetic “neighbors”) of the easy list was lower than that of the hard list (13.5 vs. 26.6). In these neighborhood density counts, a neighbor of a given target word was defined as any word that differed from the target word by a one phoneme addition, substitution or deletion in any position (Greenberg and Jenkins, 1964). For example, some of the neighbors of the word “cat” are “pat, cot, cap, scat, at.” Third, the two word lists were constructed such that the neighborhood frequency (the mean frequency of the neighbors) of the easy list was much lower than that of the hard list (38.3 vs. 282.2 per million). The net result of these three lexical manipulations was that the easy list consisted of a set of words that occur frequently in the language, and that have few phonetically-similar, low-frequency neighbors with which they could be confused. In contrast, the hard list consisted of words with many neighbors that are high in frequency relative to the target word. Thus, easy words “stick out” from sparse neighborhoods; hard words are “swamped” by dense neighborhoods. Finally, in order to ensure that subjects would be familiar with all of the words in both lists, all words had been judged as highly familiar by normal-hearing adults, i.e. received a familiarity rating of 6.7 or higher on a 7 point scale where 1 indicated the lowest and 7 indicated the highest degree of familiarity (Nusbaum et al., 1984).

Digital Speech Recordings

Ten talkers (five males and five females) were recorded producing both the easy and the hard word lists at three different speaking rates (fast, medium, and slow), giving a total of 4500 tokens (150 words x 3 speaking rates x 10 talkers). None of the talkers had any known speech or hearing impairments at the time of recording, and all were native speakers of General American English. The talkers were recruited from the Indiana University community and were paid for their participation. All talkers were told in advance that they would be asked to produce three word lists of 150 words each at three different speaking rates. Each individual talker was allowed to regulate his/her own speaking rate, so long as the three rates were distinct. An analysis of the word durations for each talker at each of the three rates confirmed that each talker successfully produced the three lists with three distinct speaking rates. The mean durations were 809 ms (range 576-1030 ms), 525 ms (range 466-579 ms), and 328 ms (range 264-

413 ms) for the slow, medium, and fast words, respectively, confirming that the talkers were successful at producing three distinct rates of speech.

All 150 words (75 easy plus 75 hard) were presented to the talkers in random order on a CRT monitor in a sound-attenuated booth (IAC model 401A). The stimuli were transduced with a Shure (SM98) microphone, and digitized on-line (16-bit analog-to-digital converter (DSC Model 240) at a 20 kHz sampling rate). The recordings were all live-monitored by an experimenter for gross misarticulations and hesitations. Each individual digital file was then edited by hand to remove the silent portions at the beginning and end of each word file. The average root means square amplitude of each of the digital speech files was then equated. Finally, the files were converted to PC WAV format for presentation to listeners using a PC-based perceptual testing system (Hernandez, 1995).

Speech Intelligibility Tests

Speech intelligibility scores were collected from independent groups of ten normal-hearing listeners, each of whom transcribed the full set of 150 words from one talker at one speaking rate, for a total of thirty groups of ten listeners (10 talkers x 3 speaking rates). The listeners were all recruited from the Indiana University community and were paid for their participation. None of the listeners reported any prior history of a hearing or speech impairment at the time of testing. The words were presented to the listeners in random order over matched and calibrated Beyer DT-100 headphones via a PC-based perceptual testing system (Hernandez, 1995). The words were presented in the clear (no background noise was added) at a comfortable listening level (70 dB SPL). On each trial, the listeners heard the word and then typed in their response on the computer keyboard. Each listener received a different randomization of the 150 test words. In the data scoring, a word was counted as correct if all of the letters were present and in the correct order, if all the letters were present but not in the correct order (to allow for obvious typographical errors), or if the transcribed word was a homophone of the intended word.

These transcription scores provided a means of investigating the effects of speaking rate (fast vs. medium vs. slow) and lexical discrimination (easy vs. hard) on isolated word intelligibility. Additionally, since each group of listeners transcribed the full set of 150 words by a single talker at a single rate in a single transcription session, we could also use these intelligibility data to investigate whether listeners adapted to talker-specific characteristics to the extent that the intelligibility scores improved from the beginning to the end of the transcription session. We hypothesized that this kind of listener-talker “attunement” on the part of the listener, which occurs over the course of exposure to the speech of a particular talker, would interact with the lexical (easy vs. hard) and speaking-rate (fast vs. medium vs. slow) factors such that there would be a greater listener-talker adaptation effect as the other factors increased in difficulty. Such a finding would indicate that listener-talker familiarity could compensate for the word recognition difficulties associated with increased speaking rate and lexical discrimination.

Results

Figure 1 shows the overall percent correct transcription scores across all talkers and listeners for the easy and hard word lists at each of the three speaking rates. As expected based on earlier investigations of the effects of these lexical characteristics on speech perception (Pisoni et al., 1985; Luce, 1986; Luce et al., 1990; Luce and Pisoni, 1998), the easy word lists were consistently transcribed more accurately than the hard word lists. As shown in Table I, the higher transcription accuracy for the easy list relative to the hard list held true for most of the speakers at all three speaking rates. The exceptions were for Talkers 1, 5, 6 and 9 at the slow rate, where there was no easy-hard difference, and for Talker 6 at the medium rate where there was a very small advantage for the hard word list. Thus, the word identification advantage for easy words over hard words is a highly robust effect that generalizes across multiple talkers and speaking rates. The critical difference between easy and hard words is that hard words require the

listener to discriminate between a large set of competitors. In other words, in order to recognize a hard word correctly, the listener must make fine phonetic discriminations at the segmental level. The fact that this effect is observed even under highly favorable listening conditions suggests that the ability to make fine phonetic discriminations is a skill that is prone to disruption, and as such is likely to be affected even more when conditions are less than favorable such as in the case of non-native listeners, noisy listening environments, or hearing-impaired listeners.

 Insert Figure 1 about here.

Although Figure 1 also shows a substantial decline in transcription accuracy for the fast rate relative to the medium and slow rates for both the easy and the hard word lists, there was little difference in transcription accuracy between the slow and medium rate words. This pattern of results was somewhat surprising in view of the fact that, on average, the slow words were about 54% longer in duration than the medium words (see also Torretta, 1995). Thus, it appears that isolated word intelligibility is not enhanced by slowing the speaking rate. However, this may have been due to a ceiling effect for word intelligibility in quiet listening conditions.

These initial observations were all confirmed by a repeated-measures ANOVA (nested design) with both speaking rate (fast, medium, slow) and lexical discrimination (easy, hard) as within subject variables, and the intelligibility scores for each talker in each condition averaged across all ten listeners as the dependent variable (see Table I). There was a main effect of speaking rate ($F(2,18)=7.456$, $p=.0013$), and a main effect of lexical discrimination ($F(1,18)=20.111$, $p=.0015$). An examination of the contrasts showed a significant difference (at the $p<.005$ level) between the fast and medium rates for both the easy and the hard words, but no difference between the medium and slow rates for either the easy or the hard words. Furthermore, at all three rates, the easy versus hard difference was significant at the $p<.005$ level.

Table 1.

Mean intelligibility scores across all ten listeners for the easy and hard word lists by each talker at each speaking rate.

Talker	Easy			Hard		
	Slow	Medium	Fast	Slow	Medium	Fast
1	91.07	92.40	86.13	82.67	81.20	72.27
2	94.40	95.47	94.27	94.80	94.40	89.33
3	94.67	94.00	94.93	88.93	89.60	92.53
4	92.40	96.00	88.27	88.67	87.20	78.00
5	94.00	94.40	86.27	89.47	91.33	75.47
6	92.93	93.87	91.87	92.80	90.40	89.73
7	90.67	89.20	89.47	91.07	90.26	87.87
8	94.93	96.27	92.93	93.60	88.40	89.47
9	95.07	96.67	95.73	92.40	92.13	84.40
10	95.07	98.40	96.27	94.93	95.46	90.67
mean	93.52	94.67	91.61	90.93	90.04	84.97

The next step in our analysis of these intelligibility data was to investigate whether isolated word intelligibility improves as the listener becomes accustomed to the talker's voice. In particular, we wondered whether hard words that were presented later in a transcription session would be more accurately transcribed than hard words presented earlier in the session. We were interested in whether listener-talker adaptation might compensate for the processing difficulties introduced by the lexical discrimination factor.

Figure 2 shows the percent correct transcription scores for the easy and hard words in the first quartile (Q1) and fourth quartile (Q4) of the transcription sessions at the slow (left panel), medium (middle panel), and fast (right panel) speaking rates. In each case, the first and fourth quartiles were taken as the first and last 38 words presented to the listeners, respectively. Because each listener received a different randomization of the 150 words, differences due to particular items could be controlled over the entire group of listeners. As shown in Figure 2, hard words presented in the last quartile were generally more accurately transcribed than hard words presented in the first quartile at all three speaking rates. In contrast, there was no noticeable difference between easy words presented in the first and fourth quartiles at all three speaking rates, probably due to a "ceiling" effect for easy words.

Separate ANOVA's for each speaking rate showed that for all three rates there was a main effect of quartile, such that the Q4 intelligibility scores were consistently higher than the Q1 intelligibility scores [Slow: $F(1,9)=9.670$, $p=.013$; Medium: $F(1,9)=13.605$, $p<.005$; Fast: $F(1,9)=22.977$, $p<.001$]. There was also a main effect of lexical discrimination, such that easy words had higher intelligibility scores than hard words [Slow: $F(1,9)=6.341$, $p=.033$; Medium: $F(1,9)=15.165$, $p<.004$; Fast: $F(1,9)=19.272$, $p<.002$]. Furthermore, the quartile by lexical category interaction was significant for the medium rate and approached significance for the fast rate [Slow: $F(1,9)=2.349$, $p=.160$; Medium: $F(1,9)=6.729$, $p<.03$; Fast: $F(1,9)=4.312$, $p=.068$]. Post-hoc tests showed that at all three speaking rates the Q4-Q1 difference was significant for the hard words (at the $p<.05$ level), but not for the easy words.

 Insert Figure 2 about here.

These data on the relative time-course of word recognition indicate that as the listener becomes accustomed to the talker's voice and articulatory patterns, the intelligibility difficulty introduced by the lexical characteristics of hard words relative to easy words is "neutralized" to a large extent. Furthermore, a comparison of the first and fourth quartile intelligibility scores across the three speaking rates (see Table 2) showed that the intelligibility of fast rate words in the fourth quartile (mean = 89.67%) approached the intelligibility scores for the slow and medium rate words in the first quartile (means = 90.80% and 90.05%, respectively). In other words, the listener's experience with the talker's speech compensated for the intelligibility difficulty introduced by the fast speaking rate. In general, this pattern of results suggests that listener-talker adaptation and attunement are important factors that interact with other talker- and item-related factors, such as speaking rate and lexical discrimination, in determining the overall intelligibility of normal speech by normal listeners.

Table 2.**Mean intelligibility scores for each speaking rate in the first and fourth quartile.**

	First Quartile	Fourth Quartile
Slow	90.80	92.90
Medium	90.05	93.04
Fast	85.98	89.67

Finally, we were interested in investigating the degree to which a talker's overall intelligibility score across all listeners and across all words correlates with the difference between his or her easy and hard word intelligibility scores¹. We predicted that talkers who had smaller intelligibility differences between easy and hard words would have higher overall intelligibility scores across both easy and hard words since a small easy-hard difference would suggest that the talker is sensitive to the perceptual difficulty of a hard target word and is likely to have made compensatory articulatory adjustments in the production of hard words to assist the listener. Based on these predictions, Wright (1997) recently found that vowels in hard words were consistently hyper-articulated relative to vowels in easy words. Thus, we expected to find significant negative correlations across our ten talkers between overall intelligibility across all words and the intelligibility difference between easy and hard words. Across all three rates, we found a significant negative correlation of $-.697$ ($p=.023$), suggesting that talkers who have smaller easy-hard intelligibility differences have higher overall intelligibility scores. This negative correlation was slightly stronger for the fast and slow rate tokens: $-.756$ ($p=.008$) and $-.748$ ($p=.010$), respectively. However, it was weaker and failed to reach significance for the medium rate words: $-.454$ ($p=.195$). In general, however, it appears that the smaller the intelligibility difference between easy and hard words the greater the overall intelligibility score of a particular talker. This pattern may be based on a strategy the talker uses to insure greater articulatory precision in the production of hard words to compensate for the perceptual difficulty imposed by the lexical competition characteristics.

Summary and Discussion

The primary goal of this initial experiment was to examine the combined effects of various talker-, item-, and listener-related factors on spoken word recognition by native listeners by using a carefully constructed multi-talker, multi-listener speech database. Results showed that overall word intelligibility was adversely affected by lexical discriminability: easy words had higher overall intelligibility than hard words. This effect of lexical discrimination was a listener-related factor that results from knowledge on the part of the listener regarding the sound-based structure of the lexicon of the language. We also observed a decline in overall intelligibility for the fast speaking rate: slow and medium rate words both had higher overall intelligibility scores than fast rate words. This speaking rate effect was a signal-related factor that presumably results from acoustic-phonetic adjustments on the part of the talker when he or she is required to consciously adjust speaking rate. We also observed a complex relationship between the various factors whereby the difficulties imposed by one factor, such as a fast speaking rate or an inherently difficult lexical item, could be overcome by the advantage gained through the listener's experience with the speech of a particular talker. Finally, we found that the easy-hard intelligibility difference was negatively correlated with overall intelligibility across the group of talkers, suggesting that a talker-related strategy for achieving higher overall speech intelligibility was to "hyper-articulate" hard words to compensate for the high degree of lexical competition for these words (see also Wright, 1997). Taken together, these data demonstrate that speech intelligibility is subject to a multitude of highly dynamic variables that have their basis in specific talker-, item-, and listener-related factors. These

findings underscore the view of speech communication as an adaptive process from both the talker's and the listener's points of view. In the next experiment, we extended our investigation of factors affecting recognition of spoken words to another listener population, namely, non-native listeners of English.

EXPERIMENT 2

Spoken word recognition by non-native speakers depends on a wide range of skills including novel contrast categorization, the adoption of non-native processing strategies, and vocabulary development in the target language. Current research on non-native speech perception has been dominated by the study of the first of these skills, namely, non-native phoneme perception (e.g., see Strange (1995) and references therein). This earlier research has focused on understanding the effects of the first language phoneme inventory on the ability to discriminate and identify second language phonemic contrasts. The findings have led to the development of several models that account for the different degrees of difficulty associated with the perception and production of different non-native contrasts (Best, 1995; Flege, 1995), and has provided researchers with information about the effects of linguistic background on speech sound perception and categorization. However, we still do not know to what extent the perception of larger linguistic units depends on fine-grained phoneme discrimination and identification. Is accurate phoneme categorization a necessary prerequisite for accurate word recognition? Or, does novel phonemic contrast perception arise from the ability to recognize word-sized units that contrast minimally with each other?

A similar issue is central to the study of first language acquisition in children. Current research in infant speech perception and early word learning has suggested that the system of meaningful contrasts develops only after infants have developed the skills to perceive and extract words-sized units from the speech stream. In the words of Jusczyk (1997),

“...it is unlikely that filling in a phonetic inventory is the primary force that drives infants' acquisition of the sound structure of their native language. Rather, the acquisition of phonemic categories and phonemic distinctions falls out of learning to segment and recognize words in the fluent speech of one's native language.” (page 109)

While adult second-language acquisition differs in many respects from infant first-language acquisition, it is likely that the need to recognize words is the primary force behind both processes. According to this point of view, sensitivity to non-native phonemic contrasts develops in response to the addition of new lexical items that reflect the specific contrast in question. While the adult second-language learner has the advantage of mature analytic skills that can aid the perception of phonological features at the segmental level, it is likely that novel phoneme perception can function in a linguistically meaningful manner only once the contrast in question signals a known lexical contrast. In other words, acquiring knowledge of the sound-based structure of the target language lexicon is just as important a factor in non-native speech perception as gaining experience with the structure of the target language phoneme inventory. In order to fully understand non-native speech perception, we need to investigate recognition of word-sized units by non-native listeners using stimulus materials that are well controlled in terms of the sound-based structure of the target language. Accordingly, in Experiment 2 we used the multi-talker database developed in Experiment 1 to investigate spoken word recognition by non-native listeners.

In particular, we wanted to determine whether non-native listeners of English show the same effect of lexical discriminability as native listeners. Specifically, do non-native listeners have greater difficulty with “hard” words than with “easy” words? This outcome would suggest that non-native listeners develop lexicons of their second language using the same sound-based organization as native

listeners. We also wanted to know how non-native listeners perform under conditions of high stimulus variability due to a change in talker across items in a spoken word list. Previous research has shown that native listener word recognition is more accurate when surface characteristics, such as talker-related characteristics, remain consistent across items in a list (Mullennix et al, 1989; Sommers et al., 1994). Furthermore, as we found in Experiment 1 above, native listeners show evidence of adaptation and tuning to these talker-related characteristics especially under conditions where word recognition is more difficult (i.e., lexically “hard” words.) Thus, as a step towards gaining further insight into the factors affecting recognition of spoken words, we wanted to see how non-native listeners cope with talker variability across items in a list.

Furthermore, in this experiment we assessed both spoken word recognition and written word familiarity. This comparison across these two modalities in adult second-language learners allowed us to look at non-native aural proficiency and non-native lexical development independently of each other. This independent measurement of non-native spoken word recognition and lexical development was particularly important because these two abilities might be confounded in non-native listeners. We know that spoken words are recognized by native listeners in the context of other words and that words requiring fine phonetic discrimination are more difficult to recognize (Luce and Pisoni, 1998). Thus, we might expect that non-native listeners will have particular difficulty with hard words since we know that fine phonetic discrimination of foreign language phonemes is particularly difficult for non-native listeners. However, lexically hard words are defined as words of lower frequency in the language thus we might expect non-native listeners to be less familiar with hard words than easy words and therefore less likely to recognize them correctly. Thus, in order to understand the interaction of phonetic and lexical effects on non-native word recognition independently of word familiarity, we need to obtain independent measures of spoken word recognition and knowledge of the lexicon of the target language. Accordingly, we obtained both measures in Experiment 2.

Method

Subjects

Two groups of subjects participated in this experiment. The first group, the experimental group, included 20 non-native listeners of English who were recruited from the Indiana University community. They ranged in age from 21 to 33 years, and had studied English for 2 to 18 years. There were 8 males and 12 females. They came from diverse language backgrounds with the breakdown as follows: 6 Koreans, 4 Chinese, 3 Russians, 2 Japanese, 2 Spanish, 1 Bengali, 1 Nepali and 1 Dani. The second group, the control group, included 20 native English listeners. They were also recruited from the Indiana University community, and ranged in age from 20 to 42 years. There were 6 males and 14 females. All subjects were paid for their participation. None reported any known speech or hearing impairment at the time of testing.

Stimuli and Procedures

All subjects performed two separate tasks. The first task was a spoken word recognition task in which subjects heard a word over headphones and typed what they heard into a computer keyboard. The stimuli for this task came from the multi-talker database of words that was described in Experiment 1 above. Only words from the medium rate set were used in this experiment. Two separate lists of words were compiled. The first list consisted of 78 items produced by a single female talker whose mean intelligibility score for the medium rate words was closest to the average intelligibility score across all 10 talkers. Within this “single-talker” list, half of the words (n=39) came from the easy list and half of the words (n=39) came from the hard list. The second list consisted of 72 items, half of which were easy (n=36) and half of which were hard (n=36). The items in this “multiple talker” list were produced by the 9 remaining talkers, 4 females and 5 males, with each talker producing 4 of the easy words and 4 of the

hard words. The single- and multiple-talker lists were presented to the listeners binaurally over matched and calibrated (DT-100 Beyer) headphones at a comfortable level (70 dB SPL). The order of list presentation (single-talker versus multiple-talker) was counter-balanced across listeners. Within each list, the words were presented in random order and the listeners were instructed to type the word they heard into the keyboard. Each word was presented only once with no possibility of repetition. However, the experiment was self-paced, allowing the listeners to correct spelling errors or make best guesses when entering their responses on the computer keyboard.

The second task was a word familiarity rating task in which subjects rated their familiarity with a list of English words. In this task, subjects responded to 300 words that were presented in standard American English orthography on a computer monitor. Subjects entered their response by pushing a button on a custom-made 7-button box after the word appeared on the screen. Subjects were instructed to use a 7-point scale where 1 indicated “I have never seen this word,” 4 indicated “I have seen this word but don’t know its meaning,” and 7 indicated “I know this word.” Of the 300 words used in this task, 150 came from the “easy” and “hard” lists used in Experiment 1 and in the spoken word recognition task of Experiment 2. The remaining 150 words were a subset of words that were taken from a longer list of words that had been used in a previous familiarity rating task with native listeners (Lewellen et al., 1993). Of these, 50 received low ratings, 50 received medium ratings, and 50 received high ratings from the native listeners in this earlier study.

Taken together, the list of 300 words used in the present experiment included all of the words used in the spoken word recognition task plus a set of words known to cover a wide range of familiarity ratings from native listeners. Thus, this list provided us with a measure of the receptive vocabulary size of our non-native subjects relative to native subjects. Furthermore, these familiarity rating data allowed us to assess the extent to which non-native spoken word recognition depends on familiarity with the target word. All subjects performed the familiarity rating task after having completed the spoken word recognition task.

Results

Spoken Word Recognition

Figure 3 shows the overall percent correct transcription scores for the easy and hard words for the control subjects (left panel) and for the non-native subjects (middle panel) in the single-talker and multiple-talker conditions, respectively. As expected, the control subjects displayed higher overall word recognition scores than the non-native listeners. The overall mean and standard deviation for the control subjects were 89.22% and 6.83%, respectively. For the non-native subjects, the mean and standard deviation were 62.73% and 12.24%, respectively. However, both subject groups showed similar patterns of results across the single- and multiple-talker conditions, as well as across the easy and hard words. For both groups, the overall percent correct recognition rate in the multiple-talker condition was lower than in the single-talker condition, indicating that both groups were able to take advantage of the consistent talker information in the single-talker condition. The difference between word recognition accuracy scores in the single- and multiple-talker conditions was 7.2% for the control subjects and 7.9% for the non-native subjects. Additionally, both groups showed higher recognition accuracy scores for the easy than for the hard words. However, there was a strong interaction between subject group and lexical category. Whereas the control subjects showed a difference of 4.3% between easy and hard words, the non-native subjects showed a much larger difference of 25.2% and this was present for both the single- and multiple-talker conditions. The pattern of results displayed in Figure 3 was confirmed by a 3-factor ANOVA with Group (non-native, control), Talker (single, multiple) and Lexical Category (easy, hard) as factors. This analysis showed main effects of Group ($F(1,38)=100.62, p<.0001$), Talker ($F(1,38)=35.38, p<.0001$), and Lexical

Category ($F(1,38)=128.34$, $p<.0001$). There was also a significant Lexical Category x Group interaction ($F(1,38)=64.53$, $p<.0001$). None of the other interactions was significant.

 Insert Figure 3 about here.

The highly significant difference in word recognition accuracy between the single- and multiple-talker conditions for both groups of subjects suggests that the ability to take advantage of consistent surface information about a particular talker's voice is a skill that transfers easily from first to second language. Conversely, this result suggests that the processing difficulty introduced by a high degree of variability in the stimulus set due to a change in talker from item to item is not particularly acute for non-native listeners. Rather, all listeners regardless of language background respond similarly to indexical, surface-level variability. The highly significant easy-hard word difference for the non-native listeners suggests that these listeners are developing an English language lexicon with the same sound-based structure as the native English listener lexicon. However, the fact that the non-native listeners showed much lower scores for hard words relative to the control subjects suggests that they have much greater difficulty when fine phonetic discrimination at the segmental level is required by the task. Nevertheless, these non-native subjects appear to be recognizing spoken words relationally in the context of other words they know, although at somewhat lower levels of accuracy relative to native speakers.

Familiarity Ratings

Figure 4 shows the mean familiarity ratings given by the control and non-native subjects in response to the five word lists used in this task. The words in the low, medium, and high lists had been classified into these three categories based on earlier ratings from a large number of native listeners (Lewellen et al., 1993). The easy and hard lists contained the same easy and hard words that were presented to the subjects in the spoken word recognition task. On the low, medium, and high lists, the non-native listeners gave substantially lower familiarity ratings than the control subjects. However, both groups showed the expected pattern of increasing familiarity ratings from the low to the medium to the high word lists, suggesting that this task is indeed a valid measure of word familiarity in non-native listeners.

 Insert Figure 4 about here.

Of greater interest for this study are the results of the familiarity rating task with the easy and hard words lists. These words were originally selected so that native listeners would be highly familiar with all the test words. This native listener familiarity is indicated in Figure 4 by the high mean ratings for the control subjects (striped bars) for both the easy (mean rating = 6.9) and hard (mean rating = 6.9) words lists. In contrast, the non-native listeners (black bars) had a high mean familiarity rating for the easy words (mean rating = 6.6) but their ratings for the hard words were much lower (mean rating = 5.1). Thus, the pattern of familiarity ratings parallels the pattern of word recognition scores for the non-native subjects, suggesting that part of their difficulty in recognizing hard words may stem from a lack of familiarity with the words themselves rather than from a difficulty with fine phonetic discrimination.

In order to further test the relationship between word familiarity and spoken word recognition in the non-native listeners, we re-analyzed the non-native spoken word recognition data by limiting our analysis to only those words that received a familiarity rating of 6 or higher. In this manner, both the non-native and the control subjects' scores reflect word recognition accuracy for words that are judged to

be highly familiar to the listeners. Figure 3 (right panel) shows the non-native subjects' mean word recognition accuracy scores in the single and multiple talker conditions only for the easy and hard words that received a familiarity rating of 6 or higher. On average, across all 20 non-native subjects, 105 of the original 150 words (70%) were included in this analysis. This includes an average of 54/75 (72%) of the easy words and 51/75 (68%) of the hard words.

As shown in Figure 3, the general pattern of results that we observed for all words (middle panel) is present even when we remove the confounding factor of word familiarity (Figure 3 right panel). A 3-factor ANOVA (on only the high familiarity non-native word recognition scores) with Group (non-native, control), Talker (single, multiple) and Lexical Category (easy, hard) as factors showed main effects of Group ($F(1,38)=80.164$, $p<.0001$), Talker ($F(1,38)=25.567$, $p<.0001$), and Lexical Category ($F(1,38)=71.263$, $p<.0001$). There was also a significant Lexical Category x Group interaction ($F(1,38)=34.005$, $p<.0001$). None of the other interactions were significant.

Thus, while non-native word recognition accuracy may be limited by familiarity with the lexical items, even when we controlled for familiarity, we observed a strong easy-hard effect for these listeners. This pattern suggests that non-native listeners develop second-language mental lexicons that follow the same sound-based structure as the first-language mental lexicon, and that the fine phonetic discrimination required for accurate hard word recognition is especially difficult for these listeners.

Correlational Analyses

In order to further investigate some of the factors that underlie non-native listener responses to spoken words, we performed a series of correlational analyses between the mean spoken word recognition accuracy scores for each of the 20 non-native subjects and various demographic factors that we obtained from subjects at the start of the data collection sessions. We also performed a similar set of correlational analyses between these demographic variables and the mean familiarity rating score for each of the non-native subjects. In each case, we performed separate correlations for the easy word scores and the hard word scores. Table III shows the results of these correlational analyses for the variables of greatest interest. For each variable, the numbers in parentheses represent the range of scores across all 20 subjects.

Table 3.

Correlations between spoken word recognition accuracy, word familiarity ratings and demographic variables. Numbers in parentheses refer to the range for each variable.

	Word Recognition		Familiarity Ratings	
	Easy (3.95-7.00)	Hard (3.69-7.00)	Easy (60%-89%)	Hard (25%-74%)
Age of English study onset (4-23 yrs)	+0.09	-0.22	+0.04	-0.61**
# Years of English study (<1-18)	+0.11	+0.28	+0.17	+0.37
# Years in English environ. (<1-8)	+0.37	+0.45*	+0.04	+0.12

(*= $p<.05$, **= $p<.005$)

For all variables, none of the correlations with the easy words were significant. This may be because the ranges of word recognition and familiarity rating scores for the easy words were more restricted than for

the hard words. There was little or no variance in these measures for the easy words. However, for the hard words several interesting correlations emerged. The data showed no correlation between age of onset of English study and hard word recognition, however, number of years in an English environment was significantly positively correlated with hard word recognition ($r=+0.45$). In contrast, there was no correlation between hard word familiarity and number of years in an English environment, however, age of onset of English study was significantly negatively correlated with hard word familiarity ($r=-0.61$). Number of years of formal English study was not significantly correlated with either hard word recognition or hard word familiarity. These correlations with the demographic variables suggest that spoken word recognition is an essentially aural skill that requires exposure to spoken language, whereas written vocabulary development is most aided by an early onset of formal second-language study.

Summary and Discussion

In Experiment 2 we investigated some of the characteristics of non-native spoken word recognition as they relate to known characteristics of native spoken word recognition. We found that spoken word recognition by non-native listeners displayed the same overall patterns as for native listeners. Specifically, both groups of listeners recognized words more accurately when all the test words were spoken by the same talker relative to a condition where the talker changed from item to item. This finding suggests that the ability to take advantage of consistent surface phonetic information, such as consistencies in the talker's voice and articulatory patterns, is a language-independent skill that transfers easily from first-language to second-language word recognition.

We also found that both groups of listeners were more accurate at recognizing words that were distinctive or easily discriminated in their lexical neighborhood than those that had many similar sounding neighbors with which they can easily be confused. However, this effect was much more prominent for the non-native listeners, suggesting that these listeners have particular difficulty in recognizing words that require perception of fine phonetic detail for lexical discrimination. This pattern of results held up even when we controlled for word familiarity across the easy and hard word lists.

Additionally, we found a dissociation between word recognition accuracy and word familiarity ratings with each representing a different skill. Hard word recognition correlated positively with number of years immersed in an English language environment but not with total number of years of English study or age of English study onset, suggesting that hard word recognition may be a good index of non-native aural proficiency independently of vocabulary development. In contrast, hard word familiarity was correlated negatively with age of onset of English study but not with number of years in an English language environment or with total number of years of English study, suggesting that hard word familiarity may be a good index of non-native lexicon development independently of non-native language aural proficiency.

General Discussion

Taken together, these two perceptual experiments demonstrate various characteristics of word recognition by native and non-native listeners. From a methodological point of view, our results demonstrate the utility of a large multi-talker multi-listener digital speech database for investigations into spoken language processing. An important aspect of the database that was developed in the present study was that it included a large number of stimulus items produced by a large number of talkers, that were then submitted to intelligibility tests by a large number of listeners. This approach to speech database development - one that always includes both production and perception data - has proved particularly effective as a means for investigating the effects of variability in the speech signal from both the talker's and the listener's point of view. We believe that an important goal of research in spoken language

processing is to understand both the sources of variability in the speech signal, as well as the effects of this variability for the listener (Stevens, 1996). In order to achieve this goal, we need to devise new ways of investigating the separate and combined effects of various sources of variability. Our multi-talker multi-listener database approach has proved particularly useful in this regard.

From a theoretical standpoint, the findings of the present study point to several key features of spoken language processing. The data demonstrate that spoken word recognition accuracy depends on a combination of at least three types of factors: signal-related characteristics, such as speaking rate, lexical factors, such as knowledge of the sound-based structure of the mental lexicon, and instance-specific factors, such as the listener's experience with the talker's voice and articulatory habits. All three factors combine to determine overall speech intelligibility. Of particular theoretical interest in this study is the finding that listeners adapt to the demands of the communicative situation in much the same way as talkers do. Just as talkers adapt their speech patterns to match the demands of the communicative situation, so do listeners tune and adjust their speech perception mechanisms to take advantage of surface level or paralinguistic consistencies in the signal (see also Nygaard et al., 1994; Kakehi, 1992; for similar findings). Furthermore, this type of listener-talker adaptation is apparently a feature of spoken language processing that functions independently of whether the listener is perceiving his or her native language or a foreign language. The present findings suggest that at some relatively early stage of speech processing, listeners are highly sensitive to both the indexical and the linguistic information that are simultaneously conveyed by the speech signal. Both kinds of information, indexical and linguistic, are perceived, encoded and retained in memory and play important roles in ultimately specifying the intended message of the talker.

The present findings also demonstrate a strong effect of fine-grained phonetic discrimination on word recognition. Word recognition accuracy was always compromised when fine phonetic discrimination was needed to recognize a word, as in the case of hard words spoken at a fast rate for native listeners (Experiment 1) or hard words spoken at a medium rate for non-native listeners (Experiment 2). A fast speaking rate results in reduced acoustic-phonetic cues in the signal. Similarly, non-native listeners have reduced sensitivity to crucial acoustic-phonetic cues due to their lack of experience with speech in the target language. Thus, when fine-grained discrimination is reduced, whether due to signal-related factors or listener-related factors, word recognition accuracy is reduced accordingly.

This finding suggests that while listeners may be primarily motivated to recognize word-sized units (Jusczyk 1997), their ability to access lexical items is limited by the degree of low-level acoustic-phonetic detail that is available from the signal. In other words, spoken language processing relies on both accurate phoneme categorization and knowledge of the sound structure of the target language. Any attempt to enhance speech intelligibility for non-native listeners or for native listeners under difficult listening conditions due to hearing loss or environmental noise should consider both the degree of acoustic-phonetic detail available in the signal as well as the linguistic, that is, the phonological and lexical nature of the stimulus materials to be recognized. Depending on various factors, such as those explored in this study, more or less acoustic-phonetic reduction may be tolerated without significant loss of intelligibility but this is dependent on several factors.

Finally, we end by reiterating the claim that speech communication is an adaptive process from both the talker's and listener's points of view. Lindblom (1990) sketched a theory of speech production as an adaptive process with the expectation that hyper-speech, or clear speech, transformations would enhance intelligibility. In keeping with this general research agenda, our goal has been to directly explore speech perception and production as integrated systems that both function in an adaptive manner during

real-world speech communication. The findings from the present investigation show the interplay of these two factors in spoken language processing in both native and non-native listeners.

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Figure captions

Figure 1. Mean transcription accuracy scores across all talkers and listeners for the easy and hard words at the slow, medium and fast speaking rates.

Figure 2. Mean transcription accuracy scores across all talkers and listeners for the easy and hard words in the first and fourth quartiles at the slow (left panel), medium (middle panel) and fast (right panel) speaking rates.

Figure 3. Mean transcription accuracy scores for the easy and hard words in the single and multiple talker conditions for the control subjects (left panel), the non-native subjects (middle panel), and only the items of high familiarity to the non-native subjects (right panel).

Figure 4. Mean familiarity ratings for the control and non-native subjects on words of previously determined low, medium and high familiarity (left panel), and the easy and hard words used in the word recognition task (right panel).