



# L1 and L2 phonetic reduction in quiet and noisy environments

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## Abstract

Many people share the experience of talking over noise with other on highly predictable content. There has been extensive research on predictability effects and speech in noise, but little is known about the relative strength of noise and predictability factors with respect to phonetic reduction. The current study attempts to fill this gap by examining the effects of noise, lexical frequency, repetition and word class, on the duration, mean intensity and mean F0 of vowels in speakers' L1 Mandarin and L2 English. Our results support the idea that multiple sources contribute to phonetic reduction: effects of predictability factors such as lexical frequency and word class may be dependent on language experience while the Lombard reflex is more automatic and language-independent.

**Index Terms:** Lombard, lexical frequency, repetition, word class, phonetic reduction

## 1. Introduction

How predictable a word or a segment is, and how much noise there is in the environment, are two factors that contribute to variability in speech. High predictability leads to words or segments being produced with shorter duration, lower intensity, lower F0 and more centralized vowels, e.g. [1-7]. Noise in the speech environment, however, triggers higher pitch, greater intensity, longer duration and more peripheral vowels in the speech [8-11], which is known as Lombard reflex [12]. Although many people share the experience of talking over noise about highly predictable topics, and that there are extensive but *separate* lines of research on predictability effects and Lombard reflex, little is known about the relative strength of noise and predictability factors on phonetic reduction. We attempt to fill in the gap by examining the interaction between noise and three predictability factors: lexical frequency, repetition and word class, in the context of L2 acquisition: do mechanisms that drive phonetic reduction and hyperarticulation in noisy environments work in a similar fashion in L1 and L2?

The inquiry on the interaction of predictability factors and noise is interesting in the light of ongoing debates on the mechanisms of phonetic reduction. Proponents of the listener-oriented account contend that whether or not phonetic reduction takes place depends on the talker's estimation of listeners' capability in capturing the intended message [3,13-15]. In other words, when the listeners are expected to follow the conversation easily, the speaker would employ phonetic reduction; when the listener is expected to have difficulty in understanding the message, the speaker avoids phonetic reduction. Alternatively, proponents of the speaker-oriented approach argue that phonetic reduction arises from speech production processes such as retrieval and planning [16-19]. Take repetition for example. Because of previous mention,

words of later mentions are more activated and easier to access in production, hence those words are more reduced than words in first mentions [16-19]. Results from recent studies indicate that phonetic reduction may come from multiple sources, including both speaker- and listener-oriented factors [2,20]. For instance, Lam & Watson [20] systematically manipulated repetition, which they interpreted as a speaker-oriented factor, and contextual expectedness, which they interpreted as a listener-oriented factor. They found different acoustic correlates for repetition and contextual expectedness, such that repetition affected primarily durational variation, but expectedness affected mostly intensity. Their findings highlight the need to examine the interaction between different factors that could condition phonetic reduction. We contribute to this line of discussion by studying the interaction between noise in speech, lexical frequency, repetition and word class.

We are particularly interested in examining the interaction of different factors in the context of L2 acquisition, because research on L2 English suggest that phonetic reduction is modulated by language experience. Oh & Lee [21] reported that high-proficiency Korean learners of English, like native speakers of English, demonstrated durational reduction in later mentions, but intermediate-proficiency learners did not. It is worth noting that studies comparing phonetic reduction in L1 and L2 were few in number and limited in their scope of inquiry. Oh & Lee [21] focused solely on durational effects of repetition. Another study, [22], examining effects of repetition and lexical frequency, too, focused on duration. In our study, we examine effects of three well-studied predictability factors, lexical frequency, repetition and word class, as well as environmental noise, on the duration, intensity and F0 of vowels in Mandarin-English speakers' L1 and L2.

In line with [2,10,20], we hypothesize that noise and each of the predictability factors would contribute differently to phonetic reduction. Further, following [21], we expect that predictability factors, modulated by language experience, would show different effects in speakers L1 and L2, but the effects of noise, as a reflexive response, would persist in speakers' L1 and L2.

## 2. Method

### 2.1. Materials

We prepared three sets of word pairs in Mandarin and two sets of word pairs in English. Words in each word pair had the same target vowels. All words were embedded in natural passages, with three or more occurrences. Due to space limitation, we do not provide the passages here. Interested readers may contact the authors.

With respect to the Mandarin materials, there was one set consisting of ten word pairs that contrast high vs. low frequency content words, and another set consisting of seven

word pairs that contrast word classes (content vs. function word). The Mandarin materials had one additional set of words that contrast tones (see Table 1). As there are four tones in Mandarin, we selected five word-tokens for each tone. This set is ideal for the examination of effects on F0, for the words contrasting in tone had the same segmental composition. Word frequency was obtained from the CCL Corpus for Modern Chinese (Center for Chinese Linguistics PKU) [24].

Table 1: *Material for the Mandarin tone set.*

syl structure		CV		CVV		CGV
IPA		[ma]	[sɿ]	[tsʰai]	[pau]	[ɛjɛ]
Tone1	word	<u>妈</u> 妈	<u>诗</u> 歌	<u>猜</u> 想	<u>包</u> 子	<u>些</u> 许
	freq	21280	5754	2400	1240	942
Tone2	word	<u>麻</u> 烦	<u>食</u> 物	<u>材</u> 料	<u>薄</u> 饼	<u>鞋</u> 子
	freq	10543	11786	38380	111	2017
Tone3	word	<u>马</u> 虎	<u>始</u> 终	<u>彩</u> 色	<u>保</u> 证	<u>写</u> 作
	freq	1316	31703	4935	62676	10544
Tone4	word	<u>骂</u> 他	<u>适</u> 合	<u>菜</u> 场	<u>报</u> 纸	<u>谢</u> 谢
	freq	915	14291	1170	23712	11063

Target vowels and their corresponding characters are underlined and in bold.

Similarly, the English materials consisted of a set contrasting high vs. low frequency content words and a set contrasting function vs. content words. The set of high vs. low frequency content words (see Table 2) consisted of six word pairs while the set contrasting function vs. content words had eight word pairs. Lexical frequency was obtained by using the standard simple query on the BNCweb [23].

Table 2: *Material for the English set of high vs. low frequency content words.*

High frequency		Low frequency	
word	frequency	word	frequency
<u>best</u>	355	<u>pest</u>	4.91
<u>big</u>	252	<u>dig</u>	10.7
<u>bad</u>	152	<u>pad</u>	7.72
<u>look</u>	529	<u>hook</u>	14.3
<u>lot</u>	284	<u>dot</u>	12.8
<u>alone</u>	137	<u>alight</u>	3.69

Target vowels are underlined and in bold.

## 2.2. Speakers

For the Mandarin passages, we recruited fourteen Mandarin speakers (mean age: 22.5; 3M, 11F, 10 out of the 11 female speakers also recorded the English passages).

Twelve female speakers of Mandarin (mean age: 22.7) participated in reading the English passages. They were postgraduate students at the Chinese University of Hong Kong; their English proficiency was medium to high, as eleven speakers have reported an IELTS score between 6.5 and 7.5, one speaker reported a TOEFL score of 88.

## 2.3. Procedure

For either the English part or the Mandarin part of the experiment, after the speaker is comfortably seated at the chair placed in front of a computer screen and a recorder in a

soundproof booth, the speaker is instructed to read from the computer screen. The speaker would read one passage without noise in the room and read another passage wearing a headphone where noise is played from a computer. We counter-balanced the order of noisy and quiet sessions, as well as the specific passages read in those sessions across speakers, i.e. half of the speakers recorded the noise session before the quiet session; in them, about half of the speakers read passage A in noise and passage B in quiet while the other half did the opposite. Recording was taken using a portable recorder at a sampling rate of 44100 Hz.

## 2.4. Measurements and analysis

Duration, mean intensity, and z-score normalized mean F0 of the target vowels were measured (using [25]) and separately modelled in linear mixed effect (LME) models for each set of targets (two sets in English: high vs. low content words; function vs. content words; three sets in Mandarin: English: high vs. low content words; function vs. content words; tone set). The LME models were built in R [26] using the lme4 package (version 1.1-12) [27]. Fixed factors tested included word class (for the sets contrasting function vs. content words), tone (for Mandarin data), log-transformed word frequency, environment (quiet vs. noisy) and repetition (first, second, or third mention) in the initial model. Interactions and random by-speaker or by-target slopes were added if they significantly improved the models.

## 3. Results

### 3.1. L1 Mandarin

For the Mandarin set of high vs. low frequency content words, there was a significant effect of frequency. As frequency increases, the vowel duration decreases ( $p < .001$ ) and its intensity drops ( $p = .001$ ). Tone4 tokens showed lower mean F0 for higher frequency words ( $p < .05$ ); F0 differences on Tone1 and Tone2 tokens were not significant. There was also a significant effect of noise on duration and intensity, such that vowels were longer ( $p = .004$ ) and louder ( $p < .001$ ) in noisy than in quiet environments. Tone2 and Tone4 tokens showed significantly higher mean F0 in noisy than in quiet environments ( $p < .05$ ). There was no such difference for Tone1 tokens (we happened to have no Tone3 token). In addition, repetition was also significant. Later mentions were shorter ( $p < .001$ ) but also louder ( $p < .001$ ) than earlier ones. Mean F0 did not change significantly over repetitions.

For the set of function vs. content words in Mandarin, we found no effect of word class on duration, intensity or F0. There was an effect of noise: vowels were longer ( $p < .001$ ) and louder ( $p < .001$ ) in noisy than in quiet environments. There was also an effect of repetition: later mentions were shorter ( $p < .001$ ) but louder ( $p < .001$ ) than earlier ones.

For the Mandarin tone set, there was a significant effect of noise. Vowels are longer ( $p < .001$ ), louder ( $p < .05$ ) in noisy than in quiet environments. As shown in Figure 1, all the non-high tones, i.e. Tone2, Tone3 and Tone4 tokens were higher in mean F0 in noisy than in quiet environments ( $p < .05$ ). Frequency affected the intensity, but the effect was not consistent on different tones. Tone1 and Tone2 tokens are softer in higher frequency words than in lower frequency words ( $p < .05$ ); but Tone3 tokens are louder in higher frequency words ( $p < .05$ ) while Tone4 tokens did not show a

significant difference. All tokens were softer in later repetitions than in earlier ones ( $p < .05$ ).

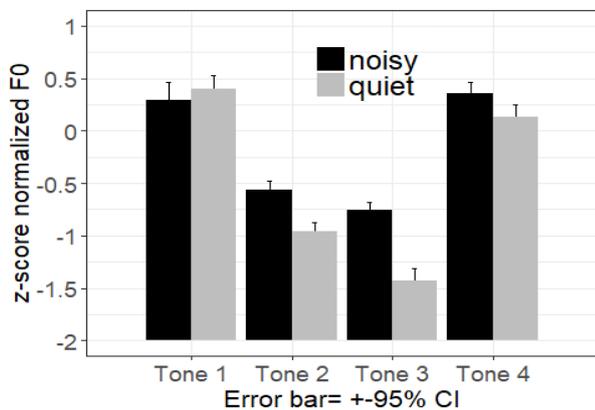


Figure 1: Effects of speech environments on mean F0 in L1 Mandarin (based on the Mandarin tone set).

### 3.2. L2 English

For the English set of high vs. low frequency content words, we did not find an effect of frequency. Vowels in higher frequency words were shorter than those in lower frequency ones, but the difference was not statistically significant. However, we did find effects of noise and repetition. The vowels were longer ( $p < .001$ ) and louder ( $p < .001$ ) in noisy than in quiet environments; F0 was lower in noisy than in quiet environments by a significant ( $p = .025$ ) but small amount (0.3 unit of z-score normalized F0). Vowels were shorter ( $p = .015$ ) and slightly higher in F0 (0.1 unit of z-score normalized F0,  $p = .004$ ) in later repetitions than in earlier ones.

For the set of function vs. content words, unexpectedly, function words turned out to be louder ( $p < .001$ ) and in higher F0 ( $p = .026$ ) than content words. Although vowels in function words were shorter than those in content words, the difference was not statistically significant. There was again an effect of noise: vowels were longer ( $p < .001$ ) and louder ( $p < .001$ ) in noise than in quiet. There were effects of frequency and repetition as well: higher frequency words were softer ( $p < .001$ ); the effect was larger on content words than on function words. Later repetitions, surprisingly, were louder than earlier ones ( $p < .001$ ).

### 3.3. Summary

In summary, noise in speech environments elicited similar effects on duration and intensity in our speakers' L1 and L2 and those effects are consistently observed across different sets of materials. In both Mandarin and English and for all the sets of words, speakers produced vowels with longer duration and higher intensity in noisy environments than in quiet environments. However, the effect of noise on F0 was less consistent across sets of materials: we did not find significant F0 differences in the function vs. content sets of words in English and Mandarin. Also, the effects were slightly different in Mandarin and English. We found lower F0 in noise than in quiet for the English materials, but F0 was generally higher in noise than in quiet in Mandarin. More specifically, all tones other than Tone1 had higher F0 in noisy than in quiet environments.

Effects of predictability factors, including lexical frequency, repetition and word class, were not consistently found across sets of words, and they often played out differently in speakers' L1 and L2. With regard to lexical frequency, we found that for the English set of function vs. content words, speakers produced higher frequency words with lower intensity than for lower frequency ones. Other than that, there was hardly any effect of lexical frequency in speakers L2 English. The effect of frequency seemed more prominent in speakers L1: we observed shortening in duration, decrease in intensity as well as lowering in F0 in the Mandarin set of high vs. low content words.

In terms of repetition, its effects on duration were clear: later repetitions were generally shorter than earlier ones (see Figure 2 and Figure 3); its effects on intensity, however, showed conflicting results: later repetitions were *louder* than earlier ones in some sets of materials (specifically: the sets of function vs. content words in both English and Mandarin, and the Mandarin set of high vs. low content words), but later repetitions were *softer* or *no different* than earlier ones in other sets of materials (specifically: the Mandarin tone set, and the English set of function vs. content words). There was little effect of repetition on F0. We found F0 difference in only one set of the materials: in the English set of high vs. low frequency words, F0 was unexpectedly higher in later repetitions than in earlier ones.

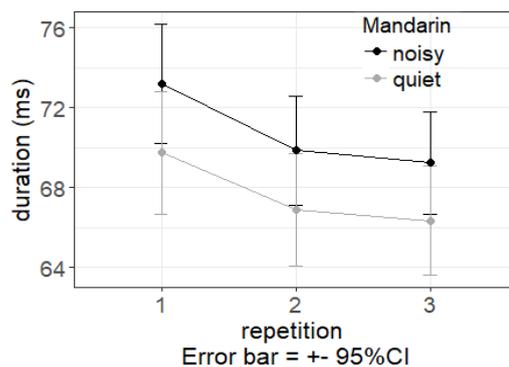


Figure 2: Effects of speech environments and repetition on vowel duration in L1 Mandarin (based on the Mandarin set of the high vs. low frequency content words).

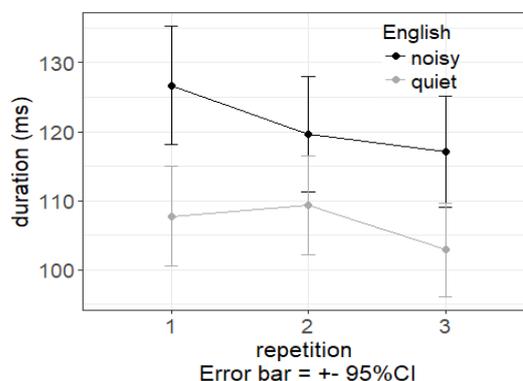


Figure 3: Effects of speech environments and repetition on vowel duration in L2 English (based on the English set of the high vs. low frequency content words).

The effects of word class were observed only in English. Surprisingly, speakers produced function words with greater intensity and higher F0 than they do for content words in their L2 English. No such difference was found in their L1 Mandarin.

#### 4. Discussion

We examined effects of noise and predictability on duration, mean intensity and mean F0 on vowels. We compared these effects in speakers' L1 Mandarin and L2 English, and used the results of the comparison as a window to assess the relative strength of the factors under discussion: noise, lexical frequency, repetition and word class. Our results indicate that noise is the strongest factor among the four, for its effects on duration and intensity were consistently observed across all sets of materials in in speakers' L1 and L2 alike: vowels are longer and louder in noisy environments than in quiet environments. Among the rest of the factors, repetition may be stronger than lexical frequency and word class, as its effects on duration were similar in speakers' L1 and L2: vowels were shorter in later repetitions than in earlier repetitions.

The finding that noise is stronger than the three predictability factors we studied attests to the robustness of the Lombard effect [12]. We found an increase in duration and intensity in noisy environments in comparison with quiet environments, which is consistent with findings in previous research [8]. We also found an increase in F0 for non-high tones in the Mandarin set of high vs. low frequency content words and the Mandarin tone set. The increase in F0 is consistent with findings in [10]. The lack of increase for the high tone (Tone1) is likely due to a ceiling effect.

It is also worth noting that among the three predictability factors, repetition seemed more robust than lexical frequency or word class. We hypothesize that the reason might be that like the Lombard effect, repetition invokes processes that are not limited by linguistic experience, but the effects of lexical frequency and word class are more closely tied to linguistic experience and the language-specific characteristics. It is possible that later mentions, due to the priming effects of previous mentions, are more activated and are accessed faster in production [16-19, 28], and that they may also involve articulatory undershoot (see e.g. [29] for discussion on articulatory undershoot in phonetic reduction; but see counter evidence in [30]). For such effects to take place, one does not need to have long-term exposure to a particular language. In contrast, one does need knowledge of and experience with a language to accumulate sensitivity to lexical frequency and word class.

The role of linguistic experience seems more prominent as we consider our results in light of previous studies on phonetic reduction in L2 English. Our results on duration confirm findings reported in [21] and [22], i.e. L2 speakers of English demonstrate durational reduction for repeated mentions and in higher frequency words. However, our results also revealed evidence that L2 speakers may not master the full range of cues in phonetic reduction as native speakers of English do, and that language experience, or proficiency, may play a role [21]. To begin with, although they did shorten the duration of vowels in higher frequency words, the reduction was not statistically significant. Given that they showed a significant difference for vowels in high vs. low content words in L1 Mandarin, their lack of robust difference in L2 English may reflect an influence of language experience. As L2 speakers,

their exposure to the language and opportunities to speak in the target language are much more limited than the native speakers. As a result, they may be less sensitive to the frequency effects or lack the articulatory proficiency to make granular yet systematic distinctions between high and low frequency words as native speakers do. Another piece of evidence showing our speakers' L2 English diverges from the native speakers' patterns is that in English, function words are expected to be weaker in intensity and lower in F0 than content words are, but our speakers' L2 English showed the opposite. One possible explanation for this divergence is L1 influence. In Mandarin, the difference between function and content words is not as clear as that in English. Monosyllabic Mandarin function words may be combined with other morphemes to form content words. Syllables in function words can be as long and loud as those in content words are. This is partly confirmed by our results on the Mandarin set for function vs. content words: speakers did not show a word class effect in their L1 Mandarin in duration, intensity or F0. The greater intensity and higher F0 for function words than content words in L2 English suggests that speakers were aware of word classes, but they failed to apply distinctions in the way native speakers do.

Overall, our results are in line with the idea that multiple sources underlie phonetic reduction processes [2,10,20]. However, different from [20], where effects of repetition was primarily associated with durational reduction and effects of expectedness with intensity weakening, our data did not show a clear one-to-one association between specific factors that could induce phonetic reduction and acoustic correlates. Rather, duration appeared to be sensitive to almost all factors investigated; the durational patterns of the effects of noise, repetition, and lexical frequency, if observed, were consistent across sets of materials. In contrast, intensity and F0 either showed conflicting patterns in different sets of materials (e.g. compared with earlier mentions, later mentions were louder in the Mandarin high vs. low frequency content words, but softer in the Mandarin tone set) or did not yield patterned differences across conditions. The greater weight on durational variations to signal differences, and the precision with which speakers are capable of manipulating durations suggest that durational variation may be a more fundamental tool in human's capacity to make linguistically relevant distinctions than intensity or F0 modulations are. However, since in our study we did not set speakers at a fixed position, and that target words were embedded in natural sentences (hence words vary in their positions) rather than in controlled carrier phrases, further research is needed to confirm our findings.

#### 5. Conclusion

Taken together, our study demonstrated intricate relations between predictability factors inducing phonetic reduction and the Lombard reflex, in speakers L1 and L2. Our results suggest that the Lombard reflex is more robust than predictability factors, as the latter may not be consistently found in L1 and L2. This is consistent with the view that multiple sources contribute to phonetic reduction: effects of predictability factors such as lexical frequency and word class may be dependent on language experience while the Lombard reflex is more automatic and language-independent.

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