Spoken Word Recognition of Code-Switched Words by Chinese–English Bilinguals

PING LI

University of Richmond

Two experiments with Chinese–English bilinguals were conducted to examine the recognition of code-switched words in speech. In Experiment 1, listeners were asked to identify a code-switched word in a sentence on the basis of increasing fragments of the word. In Experiment 2, listeners repeated the code-switched word following a predesignated point upon hearing the sentence. Converging evidence from these experiments shows that the successful recognition of code-switched words depends on the interaction among phonological, structural, and contextual information in the recognition process. The results also indicate that Chinese–English bilinguals can recognize code-switched words with the same amount of information as required by monolingual English listeners. These results are interpreted in terms of parallel activation and interactive processes in spoken word recognition. © 1996 Academic Press, Inc.

Code-switching involves the use of words from two different languages within a single discourse or even a single utterance. It is particularly frequent in bilingual communities. In Hong Kong, where both Chinese[1] and English are commonly used, code-switching occurs on a daily basis (Chan, 1993). In most cases, bilingual listeners can quickly recognize a code-switched word (henceforth CS word), without interruption of their comprehension of the sentence in which the CS word occurs. However, they may occasionally misinterpret a CS word as some other word in their native language. Even when there is no misunderstanding, there are clear differences between different CS words with respect to how easily the word can be recognized; for example, (a) the word may be easier to recognize when it carries clear phonological cues specific to the code-switched language than when it is phonologically neutral, (b) it may be easier to recognize when it is pronounced as in the code-switched language than when it is pronounced with a heavy accent of the bilingual's native language, and (c) it may be easier to recognize when it occurs in a constraining prior context than when it occurs out of context.

The present study is an attempt to provide some empirical evidence as well as a theoretical explanation for the mechanisms involved

stimuli and running the experiments. Address correspondence and reprint requests to Ping Li, Department of Psychology, University of Richmond, Richmond, VA 23173. E-mail: ping@cogsci.richmond.edu.

[1] Although there are many differences between Mandarin Chinese and Cantonese, it is generally accepted among Chinese linguists that Cantonese is a Chinese dialect rather than an independent language (e.g., Li & Thompson, 1981). For convenience, in this paper I will use the term Chinese to refer to both Cantonese (in particular) and Chinese (in general). The experimental results obtained in this study may be generalized to other Chinese dialects because of the similarity in basic phonological structure among Chinese dialects.

in listeners' recognition of CS words. It examines various psycholinguistic factors that constrain the auditory recognition of these words by Chinese–English bilinguals. In particular, this study asks the following questions: What determines whether a CS word will be correctly recognized? What determines the amount of acoustic information needed for the word's correct recognition? What affects the speed with which listeners recognize the word? And how do the various factors interact in the recognition process?

Answers to these questions will also shed light on important theoretical issues about bilingual lexical processing. For example, given that bilinguals have to identify a word from a larger pool of lexical items than monolinguals, do they need more time to recognize a CS word simply because (a) they have to search through a larger lexical space or (b) they have to switch off one language and then switch on another (e.g., as suggested by Macnamara, 1967; Obler & Albert, 1978)? Or do they need no more time than monolinguals because recognition of CS words does not involve a search or a switch mechanism but a parallel activation of all relevant lexical patterns?

Although code-switching has attracted much attention from researchers with different perspectives (e.g., linguists and sociolinguists, see Grosjean, 1982), only recently have psycholinguists studied the cognitive processes involved in code-switching (see Grosjean, in press, for a review). Research relevant to some of the above questions has been carried out mainly in the visual modality, whereby bilinguals read either pairs of words that differed in language (e.g., Schwanenflugel & Rey, 1986) or paragraphs of text in which visual materials switched languages (e.g., Chan, Chau, & Hoosain, 1983). Few studies have examined these issues in spoken word recognition in a sentential context. So far, our primary knowledge in this domain of inquiry has come from Grosjean's (1988) study of French–English bilinguals.

Grosjean (1988) set out to examine two major psycholinguistic factors in French–English bilinguals' recognition of CS words in the auditory modality. The first factor was the phonotactic structure of the CS word, which varied in whether it was phonotactically marked as belonging to a particular language (the base language — the main language of communication, or the guest language — the code-switched language). For example, initial consonant clusters (henceforth CC) are more frequent in English than in French, while initial consonant plus vowel (henceforth CV) are more frequent in French than in English. Therefore, a word with a CC configuration would prompt the bilingual listener to identify it as an English word and that of a CV configuration as a French word. The second factor Grosjean examined was the phonetics of the language that was used to produce the CS word. Grosjean distinguished true code-switches from borrowings: true code-switches are pronounced as in the guest language and thus retain phonetic cues from the guest language (e.g., an English word pronounced in English phonetics), while borrowings are phonetically adapted to the speaker's base language and have thus lost phonetic cues from the guest language (e.g., an English word pronounced using French phonetics with a French accent).

Results from Grosjean's study indicated that both phonotactic structure and language phonetics played important roles in French–English bilingual code-switch recognition. First, when the word was phonotactically marked as belonging to the guest language, it was recognized sooner and with more ease than words not marked in this way. Second, when the word was pronounced in the guest-language phonetics, it was easier to identify than words that were integrated phonetically into the base language. His results also suggested that words that had no homophonous counterparts in the two languages were recognized more quickly than words that did.

Although Grosjean's study has provided us with important information about the psycholinguistics of code-switching in speech, it is not clear that the factors he examined are the

only important ones, nor that these factors would play the same role in different bilingual situations. French and English are much closer to each other, both diachronically and synchronically, than are Chinese and English. Chinese, as a Sino-Tibetan language, differs significantly from Indo-European languages, including both English and French, in both its phonological and its grammatical structures (e.g., in its use of lexical tones, its morphemic monosyllabicity, and its lack of inflectional morphology; see Li, 1996 and Li & Yip, 1996 for a discussion of these properties in lexical and sentence processing). Thus, the patterns found with French–English bilinguals may not necessarily be found with Chinese–English bilinguals. A complete picture of bilingual spoken word recognition will emerge only if we examine various factors across diverse as well as similar languages. The present study is thus designed to examine the psycholinguistic factors underlying bilingual listeners' recognition of CS words in a rather different linguistic setting (Chinese–English) and with different research methods (see below).

Three variables are examined in this study. They include language phonetics, phonotactic structure, and context. Before presenting the experiments in detail, let me first briefly discuss some properties of these variables, properties that are particularly important for understanding the auditory recognition in the Chinese–English code-switch situation.

The first variable is a speaker output variable. It concerns the phonetics of the language in which the CS word is pronounced, as first studied by Grosjean (1988). In Hong Kong, although bilingual speakers sometimes pronounce CS words as in English, more often they adapt English words to the Cantonese phonology during code-switching, producing words that are hard for native English speakers to identify. Note that the adapted words are spontaneously produced and should be distinguished from loan words, which usually have no corresponding native forms. Frequent adaptations include softening or dropping the second consonant in a

CC sequence, softening or dropping a final stop consonant, and adapting a monosyllabic word with fricative endings to produce a disyllabic. These adaptations reflect properties of the Cantonese phonological structure, in which monosyllabic structure dominates morphemes (as in all Chinese dialects), and only CV or vowels are allowed for monosyllables (Kao, 1971).[2] In what follows, I will call the spontaneously adapted words ''borrowers'' and those that are pronounced in the English phonetics ''code-switchers'' (I will refer to them collectively as CS words). Given the phonetic properties of borrowers and code-switchers, one can expect that borrowers will be harder to recognize than the code-switchers, because they have lost phonological cues from the guest language and thus may initially mislead the listener into remaining in the base language for comprehension.

The second variable is a linguistic structural variable. It concerns the phonotactic structure of the CS words, as in Grosjean's (1988) study. Some English words contain phonotactic structures that do not exist in Chinese, for example, the CC configuration, and are therefore phonotactically marked as belonging to English only. Other English words share phonotactic structures with Chinese words, for example, the CV configuration, and are therefore phonotactically neutral between the two languages. Grosjean's manipulation of this variable involved whether the phonotactic structure of the word was more frequent in English or in French, because both CC and CV are possible in both languages, although CC favors English while CV favors French. In the Chinese–English code-switch situation, the phonotactic difference between CC and CV must be more salient, because CC simply does

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[2] One may argue that some words in Cantonese have a CVC structure, for example, those ending with /p/, /t/, and /k/. But the final consonants in these cases are unreleased stops and they occur only with a particular set of words in the *rusheng* tone whose durations are short. In other cases, the final endings consist of a nasal, /n/, /m/, or /ŋ/, whose sonorant properties are shared with vowels.

not exist in Chinese and its presence provides a clear phonological cue to the listener. One can therefore expect that CC structures will elicit faster recognition of the word than will CV structures.

The third variable is the prior context of the sentence in which code-switching occurs. Although Grosjean (1988) did not examine context effects, he clearly indicated the importance of context effects in bilingual word recognition. Unlike the above variables which have received only minimal attention and which are specific to bilingual code-switch recognition, the context variable has been extensively studied in the literature of monolingual word recognition (e.g., Grosjean, 1980; Marslen-Wilson, 1987; Onifer & Swinney, 1981; Simpson, 1981; Tabossi, 1988). Research by Grosjean and Marslen-Wilson indicates that when spoken word recognition takes place in context, only half or even less of the acoustic information of a word is needed for correct identification; in isolation, much more information is needed, and often a word may not be recognized even after its acoustic offset.

Two experiments are designed to study these variables. The first is a gating experiment, in which listeners hear increasingly longer fragments of the CS word and decide on the identity of the word on the basis of this partial or complete information (Grosjean, 1980). The second is a word-shadowing experiment, in which listeners repeat the CS word embedded in a sentence as soon as possible (Liu, Bates, Powell, & Wulfeck, in press; Slowiaczek, 1994). Consistent results from these different paradigms will lead to converging evidence, while inconsistent results may reflect effects specific to a particular paradigm.

EXPERIMENT 1

In this experiment, a word-gating paradigm was used to study Chinese–English bilinguals' recognition of CS words. The gating paradigm was developed by Grosjean and has been applied to the study of monolingual and bilingual spoken word recognition over the past decade (Cotton & Grosjean, 1984; Grosjean, 1980; Grosjean, 1988; Tyler & Wessels, 1985). Evidence has accumulated that gating is particularly useful in assessing the amount of phonetic–acoustic information needed for the correct identification of a word. There is also evidence that results from the gating task correlate highly with results obtained with other on-line tasks such as word monitoring, naming or shadowing, and cross-modal priming (Grosjean, Dommergues, Cornu, Guillelmon, & Besson, 1994; Marslen-Wilson, 1987, 1990).

In the gating task, listeners are presented with fragments of a word, one at a time in increasing duration, until the whole word has been presented. The first fragment or gate starts from the beginning of the word and has a duration of about 30–50 ms, and each successive gate increases by about 30–50 ms; this process continues until the last gate, when the whole word is presented. At each presentation, listeners are required to identify the word being presented on the basis of the information provided up to that point. The actual presentation of the auditory stimuli may be longer than the word, since the word sometimes can only be identified after its acoustic offset; in these cases, the after-offset materials are included, as in this study.

Method

Participants. Twenty-four Chinese–English bilinguals who reported no speech or hearing deficits participated in this experiment. All participants were students at the Chinese University of Hong Kong. All of them used both Cantonese and English extensively on a daily basis. Although Cantonese was their language of communication with friends and families, English was the main language for their education (they spoke to foreign educators in English and received most of their course work in English). They were all native speakers of Cantonese and had all used English for over 10 years by the time of the experiment. They took part in the exper-

iment as a laboratory requirement for credit in an introductory psychology course.

Materials and design. Thirty-two English words were selected as the target CS words (see the Appendix for a complete list). All the words are frequently used CS words in Cantonese–English bilinguals' speech, as revealed by interviews with students who frequently code-switch. They are also high in frequency in monolingual English according to Kucera and Francis (1967) ($M = 181$, $SD = 219$, skewness = 2.8). Each word was embedded in a Chinese sentence to make a natural-sounding code-switching utterance.

Half of the test words were verbs and half were nouns. In Grosjean's (1988) study only verbs were tested. In the present study both nouns and verbs were tested because they represent the two most frequent categories of words that are code-switched in Chinese–English speech (Chan, 1993). In fact, nouns are more frequently used as CS words than verbs in both Chinese–English and other bilingual situations (Grosjean, 1982; Sridhar & Sridhar, 1980).

Three independent variables were manipulated in this experiment. The first was a between-item variable, and the second and the third were within-item variables.

1. Phonotactic structure (CC vs CV): There were 16 CC items and 16 CV items in the test sentences (see the Appendix). The mean frequency of occurrence of CC and CV words was 153 and 208, respectively, according to Kucera and Francis (1967).

2. Language phonetics (code-switcher vs borrower): Each target word had two versions, one pronounced in English phonetics (code-switcher) and the other in Cantonese phonetics (borrower).

3. Context (short vs long prior context): Each target CS word was embedded in a sentence with either a short or a long prior sentential context. The short context provided semantically neutral phrases to start the sentence: the third-person pronoun *keoi,* followed either by *ge* (the possessive marker) and the

target noun or by *jiu* (want to) and the target verb. The long context provided semantically constraining information to the target CS word: the sentence started with the same third-person pronoun *keoi,* followed by the appropriate contextual phrases and then the target word.

The complete crossing of the above three variables yielded 8 test conditions. Because phonotactic structure was a between-items variable (16 CC items and 16 CV items), only the two levels of language phonetics and context needed to be created. Thus, the 32 items for the phonotactic structure was multiplied by two versions of language phonetics and two context situations, yielding a total of 128 test sentences. Sixteen Chinese words were also selected as fillers and intermixed with the code-switchers and borrowers during experimental presentation. The Chinese fillers were included to prevent listeners from treating the task as a simple identification of English words, and thus to prevent possible specialized processing strategies. Examples of the test sentences are given below (abbreviations: SC, short prior context; LC, long prior context; CL, classifier; POS, possessive marker). The Chinese words in the examples are transcribed according to the romanization scheme of the Linguistic Society of Hong Kong (1994).

CC-SC: Keoi ge *flight* jin-ci
　　　he/she POS flight delay
　　　(his/her flight is delayed).

CC-LC: Keoi daap baan jin-ci ge *flight*
　　　he/she board CL delay POS flight
　　　(he/she boarded a delayed flight).

CV-SC: Keoi jiu *sell* di fei
　　　he/she want sell CL ticket
　　　(he/she wants to sell some tickets).

CV-LC: Nei di hei-fei keoi jiu *sell*
　　　this CL movie-tickets he/she want
　　　sell
　　　(he/she wants to sell these tickets).

A separate group of 20 bilingual speakers was asked to judge the degree of constraint of the long prior context on the target CS word.

They were given the 32 test sentences with the long prior context, but without the target CC or CV word, and were asked to fill in the word. They were told to think of an English word that they would most likely use to complete the Cantonese sentence in a code-switch situation. Their responses were scored on a 1–4 scale, based on the scale proposed by Marslen-Wilson and Welsh (1978): 1 was given for a word identical to the test word, 2 for a synonym or antonym, 3 for a related word, and 4 for an unrelated word. Responses were pooled across the 20 judges, and the mean ratings were 2.8. This score was close to the high constraint condition in Marslen-Wilson and Welsh (1978), and within the range of the long context in Grosjean (1980).

Two fluent Cantonese–English bilingual speakers read the test sentences at a normal rate. One read the target words as code-switchers, and the other read them as borrowers, thus producing two versions of the same test sentences. Both readers reported frequent code-switching in their daily conversation, but their style of code-switching differed: one (an English major student) tended to say coded-switched words using English phonetics, while the other (a non-English major) using Cantonese phonetics. The phonetic–acoustic differences between the two versions were examined to ensure that these two versions represented genuinely code-switcher versus borrower versions. This was confirmed by the following major differences in an acoustic analysis: (a) in the code-switcher version the final stop consonants were clearly pronounced, whereas in the borrower version the same consonants were either dropped completely or softened as unreleased stops; (b) in the code-switcher version the CCs were clearly pronounced, whereas in the borrower version the second consonant in a CC was either omitted or softened (i.e., pronounced in shorter duration, with lower amplitude); and (c) in the code-switcher version the fricative ending /s/ was pronounced as it is in English, whereas in the borrower version it was adapted into a separate syllable /si/. As an illustration of (a) and (b) together, the word *flight* was pronounced as /flaIt/ in the code-switcher version, but as /faI/ in the borrower version.

The sentences were read directly into a Macintosh II computer and simultaneously converted into digital signals through the analog-to-digital function of the AudioMedia device. During playback, the digital-to-analog function of AudioMedia converted the digital signal and sent the sound to amplified speakers or headphones. A sampling rate of 22 kHZ with a 16-bit sound format was used for digitizing. The onset of the CS word was located as accurately as possible by inspecting speech waveforms and using auditory feedback. Each sentence was gated as follows. The first gate contained all the words up to, but not including, the target CS word. The second gate consisted of the first gate plus the first 40 ms of the target word. The third gate consisted of the second gate plus an additional 40 ms and so on, until the last gate reached the end of the word. For cases with long prior context, the last gate of the word also corresponded to the end of the sentence. For cases with short prior context, two more ''after-offset'' words occurred after the offset of the target CS word, in order to finish the sentence in a natural way: (a) a classifier or an adverb, depending on whether a noun or a verb followed, respectively, and (b) a noun or a verb providing disambiguating information to the target word.

Procedure. Before the experiment began, the experimenter explained the task in Cantonese to the listener. Listeners were told that they would be hearing Cantonese sentences, each cut into small pieces that gradually increased in length. Their task was to identify, for each piece of the sentence, the word that would occur right after the end of the first presentation (i.e., which began after the end of the first gate). They were also told that the word could be either English or Cantonese. They need to write down on the answer sheet the word that they believed they were hearing (Chinese word in Chinese characters and En-

glish word in English orthography). They were requested to make a response each time, however unsure they might be.

The 24 participants were randomly assigned to four groups of six. Each group randomly received an equal number of sentences for each condition in the $2 \times 2 \times 2$ design (i.e., four tokens in each of the eight conditions, not counting the 16 fillers). Each listener received about 400 gates in the experiment (i.e., an average of 8.3 gates for each of the 32 sentences plus the 16 fillers). The listener heard successive gates of different size for each word, but no one heard the same word token twice across the eight experimental conditions. The order of presentation for the sentences was pseudorandomly arranged such that fillers and test sentences were interspersed.

All participants did the experiment individually. The PsyScope program (Cohen, MacWhinney, Flatt, & Provost, 1993) controlled the presentation of the sentence materials. Listeners heard each sentence via two amplified speakers connected to a Macintosh II. They pressed a key to hear the next successive gate. The time interval between any two gates was controlled by the listener because different listeners may require different amounts of time to write down the answer. This procedure was different from that of Grosjean (1988), where a fixed interstimulus interval (8 s) was used. Before the test began, listeners were given a practice session in which they heard a set of separate but similar sentences. The experiment took about 1 h. At the end of the experiment, participants were requested to fill in a language-history questionnaire, giving details about their linguistic background and their daily language use (for a slightly different version of this questionnaire in English, see Liu, Bates, & Li, 1992; Appendix).

Data analysis. Two dependent variables were measured in this experiment. The first was the amount of information needed for listeners to arrive at the isolation point, the point at which listeners correctly identify the target word and do not subsequently change their minds (Grosjean, 1980). This point can be ex-

TABLE 1
Isolation Time (Percentage through Word) as a Function of Language Phonetics, Phonotactic Structure, and Context

Prior context	Code-switcher		Borrower	
	CC	CV	CC	CV
Long	48	54	75	58
	(.01)	(.01)	(.04)	(.02)
Short	61	71	84	71
	(.00)	(.02)	(.03)	(.02)

Note. Numbers in parentheses indicate error rates for particular cells.

pressed either as gate size or as percentage of the word (i.e., the isolation time divided by the length of the word); the latter measure is adopted in this study.

The second dependent variable was the number and type of erroneous word candidates that listeners proposed before the isolation point. These errors can provide us with important information about the word-isolation process, because they allow us to track the paths followed by individual listeners in the process of narrowing down various candidates to arrive at a single word.

Results and Discussion

Word-isolation data. The word-isolation results can be roughly divided into three categories depending on where the isolation point occurred: (a) before the acoustic offset of the target word, (b) after the acoustic offset of the word but before the end of the sentence, and (c) never within the sentence frame. The results indicate that 81% of target words belonged to the first category, 4% to the second category, and 15% to the third category. To assess more clearly the effects of different variables on word isolation, I calculated for each word in the first category the acoustic information needed for the word's correct identification, expressed as percentage of the word. For the words in the second and third categories, the isolation time was replaced by

the total time length of the word, following Grosjean (1980). Table 1 presents the results for isolation time as a function of language phonetics, phonotactic structure, and context, together with the rates of missing responses (i.e., responses from the third category).

Two $2 \times 2 \times 2$ (i.e., language phonetics by phonotactic structure by context) analyses of variance (ANOVA) were conducted on the data, one with participants as the random variable (F_1) and the other with items as the random variable (F_2). These analyses revealed significant main effects of language phonetics (F_1 (1, 23) = 62.75, $p < .001$; F_2 (1, 30) = 14.14, $p < .01$) and context (F_1 (1, 23) = 90.93, $p < .001$; F_2 (1, 30) = 24.30, $p < .001$). The main effect of phonotactic structure was significant in the F_1 analysis (F_1 (1, 23) = 6.17, $p < .05$), but not in the F_2 analysis (F_2 (1, 30) = 0.59, $n.s.$). There was also a significant interaction between phonotactic structure and language phonetics in both analyses (F_1 (1, 23) = 30.15, $p < .001$; F_2 (1, 30) = 10.25, $p < .01$). No other effects reached statistical significance.

First, the main effect of language phonetics confirmed the prediction that CS words, when pronounced as they are in the guest language, provide phonetic cues to the listener and are thus easier to identify than the same words pronounced in the base-language phonetics. On the average, only 58% of the word was needed for correct identification of a code-switcher, compared to 72% for a borrower.

Second, the main effect of context indicated that constraining prior context can significantly help bilingual listeners to identify the CS word. On the average, only 59% of the word was needed for correct identification if there was constraining context (i.e., long prior context), compared to 72% if there was not. These results match very well with established estimates of recognition times required by monolingual English speakers in context versus out of context. In Grosjean's (1980) original gating study, the average isolation point occurred at 199 ms for words in context and 333 ms for words in isolation. According to

the cohort model of Marslen-Wilson (1987), a one-to-two syllable content word can be recognized within about 200 ms in normal context, but may require much more time out of context. For the present set of data, the average isolation point was 190 ms for words in long prior context and 377 ms for words in short neutral context, which is very close to Grosjean and Marslen-Wilson's estimates, especially for the long context situation. Thus, the results suggest that when a CS word occurs in a natural sentential context, bilingual Chinese–English listeners need no more time to identify the word than do English listeners in a unilingual situation.

Third, the effect of phonotactic structure, though significant in the F_1 analysis, was much weaker than that of language phonetics and context, and, moreover, went counter to expectation: *more* acoustic information of the word was needed for correct identification of CC type words (67%) than for CV type words (63%), rather than less as predicted (cf. Grosjean, 1988). Interestingly, this weaker but reversed effect was due to the interaction between language phonetics and phonotactic structure. For the CC words, borrowers required much more information to recognize than code-switchers (79% vs 55%), but for the CV words, borrowers and code-switchers showed no difference (64% vs 62%). This result contrasted with Grosjean's (1988) finding that the effect of language phonetics holds only for CV words (i.e., those that were homophones in English and French), but not for CC words. According to Grosjean (1988), language phonetics does not make a difference for French–English bilinguals as long as the CS word is marked phonotactically.

The interaction between language phonetics and phonotactic structure reveals interesting new patterns in Chinese–English bilinguals' code-switch recognition. As discussed earlier, the phonetics of English versus Chinese directly affects the phonotactic structure of a CS word and thus directly affects the word's recognition by Chinese–English bilinguals. It was pointed out that CC is an illegal phonotac-

tic configuration in Chinese. When words containing CC are pronounced as borrowers, they are adapted, with the second consonant in CC either softened or completely dropped (e.g., /flaIt/becomes /faI/for *flight*). Because of the way in which borrowers modify the phonotactic configurations of CC words, the phonological cues that are supposed to be helpful become obscured or completely lost. As a result, CC words pronounced as borrowers become much harder to recognize than those pronounced as code-switchers. They are also harder than the phonotactically neutral CV words, as shown in the experiment. For example, if the word *flight* is pronounced as a code-switcher with a clear CC, listeners are prompted for its phonotactic structure of English rather than Chinese. However, if it is pronounced as a borrower (i.e., /faI/), listeners have to reconstruct the right phonotactic configuration CCVC in order to recognize it as the English word /flaIt/. Thus, it is no wonder that in the current experiment, CC borrowers required more isolation time than CC code-switchers.

In contrast to the CC words, the CV borrowers and code-switchers did not show much difference in this experiment. This result indicated that since CV structures are compatible with both Chinese and English words, language phonetics could not directly operate on them. That is, language phonetics does not change or modify the phonotactic structure in any significant way; thus, a code-switched CV word, at least initially, is perceived as compatible with both Chinese and English word candidates. This analysis was corroborated by results from the word-candidate data (see below), where language phonetics interacted with early base-language effect so that listeners initially took CS words as base-language items.

To summarize, the word-isolation data clearly indicate the importance of the variables under study, and the results are generally consistent with the predictions about the role of these variables. Moreover, the one exception (i.e., the interaction between language phonetics and phonotactic structure) indicates some new patterns characteristic of code-switching and its recognition for Chinese–English bilinguals. The data also show that bilingual Chinese–English listeners can identify a CS word with the same amount of acoustic information as required by a native English speaker to identify the word, particularly if the word occurs in a constraining context.

Word-candidate data. The gating method not only allows one to determine how much acoustic–phonetic information listeners need to correctly identify a word, but also provides insight into the underlying processes leading to the final identification of the word. During the experiment, listeners need to propose a candidate for the target word at successive points when increasing portions of the acoustic signal become available. Analysis of the various erroneous word candidates provides a window for tracking the paths followed by listeners under different conditions. In this experiment, 1508 word candidates (including the correct target words) were proposed by the 24 participants for the 32 test items. Because it is impossible to present all the data here, in the following figures, I will use a typical example to illustrate the general patterns for the candidates proposed under four different conditions.

Figure 1 presents the profile of the word candidates proposed by listeners for the target word *flight*, when there was only short prior context. On the horizontal axis is the duration of gates (in 80-ms increments, i.e., two gates), and on the vertical axis are the proposed candidates. Phonetic transcriptions of the Chinese words are typed in capital letters and English words in lowercase letters. Note that the homophones in Chinese are transcribed with the same script, for example, ''FAN'' *marriage* and ''FAN'' *separate*. The dashed line marks the offset of the word, and the asterisks indicate the number of participants who proposed the candidates. The graph is split into two halves: the upper panel represents responses to the code-switcher version, whereas the lower panel the borrower version.
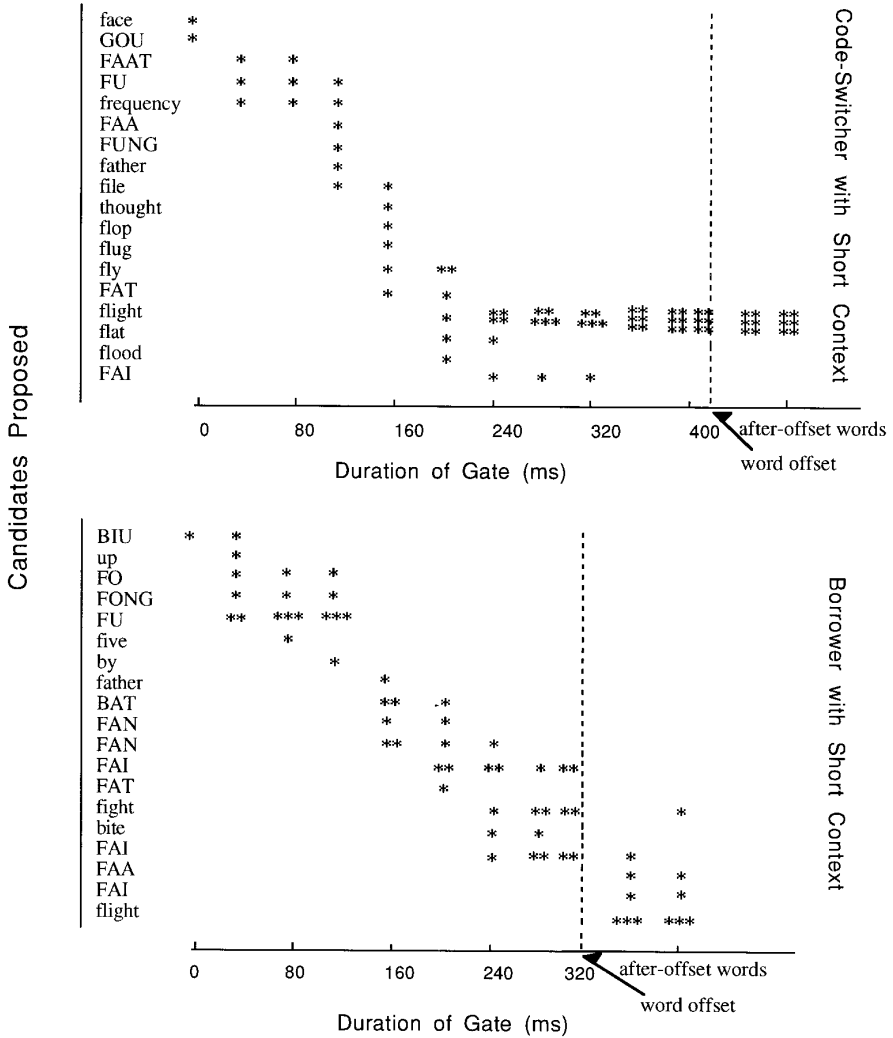
FIG. 1. Candidates proposed for *flight* as code-switcher vs borrower with short prior context.

A number of interesting results can be observed in this figure. First, consistent with earlier analysis of the role of language phonetics, *flight* said as a code-switcher was identified relatively early, at gate 7 right after the midpoint of the word by the majority of the listeners, but its borrower version was identified only after the offset of the word and by only half of the listeners. Second and more important, the erroneous candidates proposed also reflected the language phonetics difference. It was pointed out that CCs are significantly adapted in the borrower version, such that /flaIt/ becomes /faI/ (hence the shorter duration of the latter). Listeners hearing this version of the word proposed candidates such as *five, fight* in English, and FAI (light), FAI (wave), and FAN (marriage) in Chinese, all without CC. Some of these proposed words (e.g., *fight* and FAI) continued beyond the word, indicating that even until the end of the word listeners mistook the target for some other words that share part of the phonological composition of *flight*. In contrast, listeners

hearing the code-switcher version identified the CC of the word quite early, and at gate 5 they started to propose candidates such as *flat, flood, flop,* and *fly.* Although some listeners also proposed CV (C) words like *face, file,* and FU (pants) in the code-switcher version, these candidates occurred only within the first few gates when little acoustic information was available. At later gates, listeners zeroed in uniformly to a single word, the target CS word.

These results are consistent with Grosjean's (1988) proposal that the effect of language phonetics peaks at the narrowing-in stage of word recognition, not at the very beginning. Early on, when there was only little acoustic information, listeners proposed diverse candidates for both the code-switcher and the borrower. Later, when certain acoustic information of the word became available (e.g., at about gate 5 for the code-switcher in Fig. 1), listeners either recognized or failed to recognize the critical component (e.g., CC) of the word, due to the difference between code-switcher and borrower. The picture is also reminiscent of the cohort model of word recognition (e.g., Marslen-Wilson, 1987): the initial acoustic signal activates a cohort of words with the same initial phonemes (in this case words from both Chinese and English lexicons). As the acoustic signal unfolds, alternative candidates are dropped from the cohort and a single target word is selected and recognized.

A third result, as seen in Fig. 1, is that the number of Chinese versus English candidates differed depending on language phonetics. More Chinese candidates were proposed for the borrower version (12 out of 19), showing that listeners were more likely to hear a borrower as a base-language item than as a guest-language item because of the phonological adaptations with the borrowers. In contrast, more English candidates were proposed for the code-switcher version (11 out of 18), although this result did not match the overall results (see below). A further examination of the data for all the target words confirmed the pattern

for the borrower version. Of the 773 candidates proposed for the borrower targets, 59% were Chinese words and 41% were English words, a result which was consistent with the discussed pattern. However, of the 735 candidates proposed for the code-switcher targets, 54% were Chinese words and 46% were English words, a result which differed from that in Fig. 1. Thus, in general, Chinese candidates were proposed more often than English candidates for both borrowers and code-switchers.

It is very likely that, in addition to language phonetics, the so-called ''base-language effect'' was at work here. The base-language effect refers to the bias toward the base-language material in bilingual speech recognition (Grosjean, 1988; Macnamara & Kushnir, 1971). That is, when listening to a base-language stimulus, the listener expects (or is primed for) the next item to be in the same language, unless ''warned'' otherwise. To verify whether the base-language effect plays a role in the present data, I examined again for every target word the candidates that were proposed during the early stages of the word. The base-language effect was clear: of the 1264 candidates proposed during the first five gates of the word, 63% were Chinese words and 37% were English. Thus, the base-language effect interacted with the effect of language phonetics, and together these factors accounted for the larger number of Chinese candidates with both code-switchers and borrowers.

Turning now to Fig. 2, one can see that when was constraining context, the profile of the word candidates for the same target word *flight* became very different. Comparison with Fig. 1 reveals that the number of word candidates proposed was significantly reduced for both the code-switcher and the borrower, indicating that the long prior context had constrained lexical possibilities in listeners' recognition of CS words. The reduction was especially dramatic when the word was pronounced as a code-switcher: with short context, listeners proposed 18 candidates (see Fig. 1); with long context, they proposed only
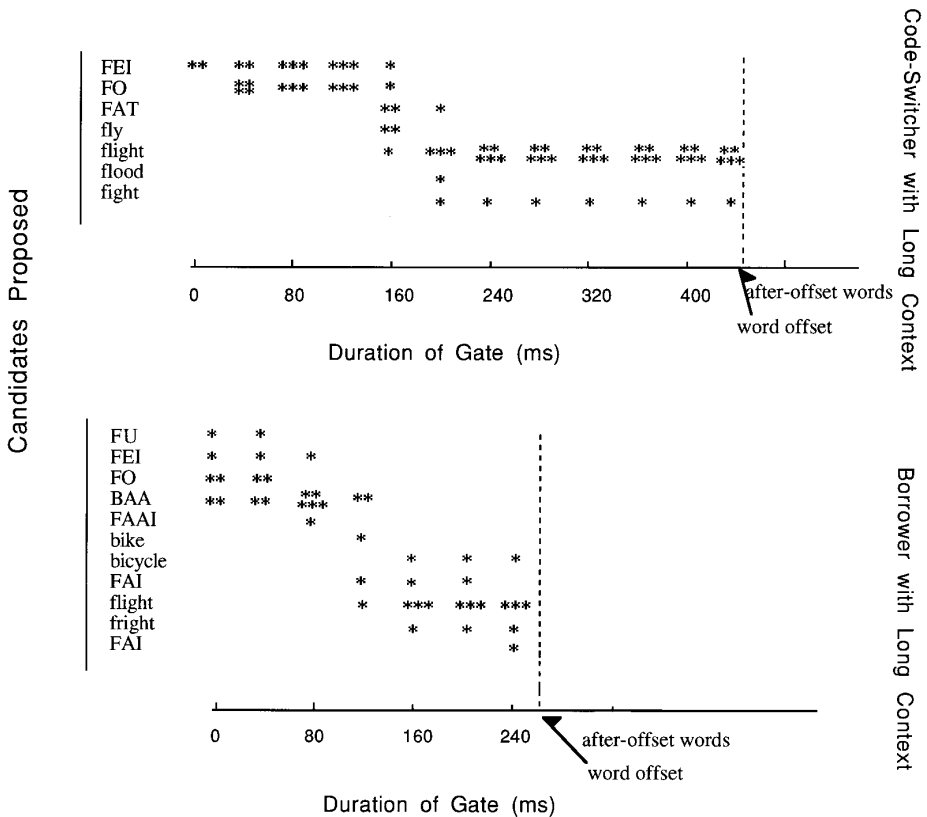
FIG. 2. Candidates proposed for *flight* as code-switcher vs borrower with long prior context.

7. The candidates that were proposed in the code-switcher version were also closer to the target (i.e., toward the later gates listeners proposed either the right target or candidates that had the right CC structure), whereas those in the borrower version were more diffuse. This pattern indicated that context had the strongest effect when the CS word was pronounced as a code-switcher. When the CS word was pronounced as a borrower, long context did not always help listeners to correctly identify the target word, although it clearly helped them to narrow down the range of lexical possibilities in recognition.

Figure 2 also indicates that, as with the results in Fig. 1, there was an initial base-language effect. For both the code-switcher and the borrower, the first five gates elicited mostly Chinese candidates. English candidates entered the picture only at later gates.

To summarize, the word-candidate data provide further evidence for the importance of language phonetics and prior context. Language phonetics affects not only how early listeners can identify the CS word but also what types of words they access in the mental lexicon and how often words are consulted and selected in the two languages. Language phonetics interacts with the base-language effect during the early stages of the recognition process, so that borrowers strongly bias the listener toward selecting forms from the base language. Constraining prior context significantly reduces the number of alternative word candidates in the recognition of CS words. It leads the recognition process more easily to

the identification of the target word, especially when the CS word is pronounced in the guest-language phonetics.

In sum, using the gating method I have obtained in this experiment consistent and complementary information from both word-isolation and word-candidate data concerning the effects of different variables in Chinese–English code-switch recognition. These include the effects of language phonetics and phonotactic structure, the context effect, and the base-language effect. The results are largely consistent with Grosjean's (1988) findings with French–English bilinguals and consistent with the role of context in monolingual word recognition. However, the interactions between language phonetics and phonotactic structure and between language phonetics and the base-language effect have revealed new patterns in Chinese–English bilinguals' processing of CS words.

EXPERIMENT 2

Results from Experiment 1 indicate that gating provides a useful way of tapping into important factors underlying bilingual word recognition. Although gating has been used successfully in many studies, questions have been raised about the possible strategic, nonlinguistic effects of the way in which gates are successively presented to listeners. The debate about whether gating results reflect on-line processes is still continuing (Grosjean et al., 1994; Tyler & Wessels, 1985). In order to derive additional evidence for or against the results in Experiment 1, I designed a second experiment, using a word-shadowing task which is generally considered a truly on-line task, to examine the same variables as were studied in Experiment 1.

The word-shadowing task utilized here is a variant of the word-shadowing or repetition or naming task used originally by Marslen-Wilson (1985) and more recently by Liu, Bates, Powell, and Wulfeck (in press) and Slowiaczek (1994). In the single-word-shadowing task used by Liu et al. listeners were asked to name the target word embedded in a sentence as soon as possible; the target word was pronounced in a voice of the opposite sex from the voice in which the sentence was pronounced. In the current experiment, there was no voice change for the target CS word because it was already in a language different from the language of the carrier sentence. Instead, listeners in this experiment were asked to repeat the word that would occur after a predesignated point. With some practice they all found the task easy to perform.[3]

Method

Participants. Twenty-four Chinese–English bilinguals who reported no speech or hearing deficits participated in this experiment. They were matched with the participants in Experiment 1 for their language background. None had taken part in Experiment 1.

Materials. The materials in this experiment were identical to those in Experiment 1. The same filler sentences as in Experiment 1 were also used, to prevent listeners from simply identifying English words. The apparatus and computer programs were also identical to those in Experiment 1. In addition, the CMU button-box (see Cohen *et al.*, 1993) was used to time listeners' response latencies. A unidirectional microphone to register listeners' vocal response was connected to the button-box through the box's voice-activated relay.

Procedure. In Experiment 1, listeners were presented with word gates of various sizes; in this experiment, they were asked to shadow the complete word only. During the experiment, listeners heard each sentence through a pair of headphones and were asked to repeat the target word aloud into the microphone. Their voice triggered the internal oscillator of the CMU button-box, and their response latencies were recorded by the PsyScope program. Listeners' response accuracy was recorded

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[3] Grosjean (personal communication) has piloted some experiments in French using predesignated-point shadowing and obtained the classic effects of word frequency and context in monolingual word recognition. The results attest to the validity of this method.

over a remote-controlled SONY tape-recorder by the experimenter in another room. They were given a maximum of 2500 ms to respond, counting from the beginning of the sentence (the average sentence length was 1366 ms, ranging from 940 to 1750 ms). This time was sufficient for most participants to give their responses while at the same time putting them under time pressure. The overall miss rate in this experiment was 2.3%.

The 24 participants were randomly assigned to four groups of six. Each group randomly received an equal number of sentences for each condition, as in Experiment 1. The experiment consisted of four blocks of testing, each containing 12 sentences: (a) with long prior context, noun; (b) with long prior context, verb; (c) with short prior context, noun; and (d) with short prior context, verb. The order of presentation for the sentences was pseudorandomly arranged such that fillers and test sentences were interspersed. The order of presentation of the four blocks was counterbalanced across participants. No listeners heard the same target word twice.

Before the experiment began, the experimenter explained the task in Cantonese to the participant, as in Experiment 1. Listeners were told that they would be hearing Cantonese sentences, and their task was to repeat as quickly and as accurately as possible, for each sentence, the word that occurred right after a predesignated point. They were told about the predesignated point before each block of testing and took a practice session before each testing began. The predesignated point was always the last word of the phrase ''keoi (. . .) ge'' (he/she . . . POSS, for nouns) or ''keoi (. . .) jiu'' (he/she . . . wants to, for verbs). Thus, this point was, for block (a) the end of ''keoi + context + ge,'' for block (b) the end of ''keoi + context + jiu,'' for block (c) the end of ''keoi + ge,'' and for block (d) the end of ''keoi + jiu.''

All participants did the experiment individually. The experiment took about 20 minutes. At the end, participants were requested to fill

TABLE 2

RESPONSE LATENCIES (MS) AS A FUNCTION OF LANGUAGE PHONETICS, PHONOTACTIC STRUCTURE, AND CONTEXT

Prior context	Code-switcher		Borrower	
	CC	CV	CC	CV
Long	445	440	566	500
	(.01)	(.01)	(.11)	(.05)
Short	641	623	808	651
	(.02)	(.01)	(.20)	(.03)

Note. Numbers in parentheses indicate error rates for particular cells.

in the same language-history questionnaire as in Experiment 1.

Data analysis. The dependent variable was listeners' response latencies to each CS word embedded in a sentence. The raw latencies were measured from the onset of the target word to the onset of the listener's vocal response. Because the duration of the words varied (range = 127 to 570 ms, $M = 340$ ms), a new set of latency scores was calculated from the offset of the target word to the onset of the listener's vocal response and was used in subsequent statistical analyses. Listeners' response accuracy was also measured, together with their response speed.

Results and Discussion

Table 2 presents the response latencies as a function of language phonetics, phonotactic structure, and context. These results were very similar to those obtained in Experiment 1 (cf. Table 1). A Pearson product–moment correlation analysis was run on the two sets of data from the two experiments, treating the eight cells as subjects. The result yielded a correlation coefficient of .88. The consistency between the two experiments indicates that the more acoustic information listeners need to identify the word, the more processing time they need to shadow the word.

A $2 \times 2 \times 2$ (i.e., language phonetics by phonotactic structure by context) ANOVA on

these data revealed that, as in Experiment 1, there were main effects of language phonetics (F_1 (1, 23) = 38.47, $p < .001$; F_2 (1, 30) = 14.77, $p < .01$) and context (F_1 (1, 23) = 17.57, $p < .001$; F_2 (1, 30) = 57.14, $p < .001$). In Experiment 1, the main effect of phonotactic structure was significant in the F_1 analysis but not in the F_2 analysis. In this experiment, it was significant in both analyses (F_1 (1, 23) = 20.87, $p < .001$; F_2 (1, 30) = 6.79, $p < .05$). Furthermore, as in Experiment 1, the only significant interaction was between phonotactic structure and language phonetics (F_1 (1, 23) = 22.43, $p < .001$; F_2 (1, 30) = 4.04, $p = .05$). These main effects and interactions can be explained as they were in Experiment 1.

The one difference between the two experiments was in the exact direction of the interaction between language phonetics and phonotactic structure. In Experiment 1, CCs required more information to recognize than CVs when they were borrowers (79% vs 64%), but the reverse was true when they were code-switchers (55% vs 62%). In Experiment 2, CCs were harder to pronounce in both cases, although the difference between CCs and CVs were greater for borrowers (687 ms vs 576 ms) than for code-switchers (543 ms vs 532 ms). This discrepancy could be due to the task demand differences between the two experiments. Experiment 2 required listeners to make a vocal response under time pressure. It could be that CCs and CVs differ in the level of difficulty for a motor response: CCs are harder and thus take more time to produce than CVs for this subject population. This factor would not affect Experiment 1, in which listeners wrote down their responses in an untimed situation.

The error rates in Table 2 showed that listeners were in general very accurate in shadowing the words. The only high error rates occurred with the borrower words that had CC initials. These words were harder to identify and consequently harder to shadow, because they were phonologically adapted to the base language. They had longer isolation times in Experiment 1 (some were never isolated), and

elicited slower shadowing times in this experiment.

In sum, results from Experiment 2, obtained with a different method, provide additional evidence for the patterns observed in Experiment 1 regarding the role of language phonetics, phonotactic structure, and context in Chinese–English bilingual code-switch recognition. These variables significantly affect the speed with which listeners can recognize and shadow the words. The data are also consistent with those from previous research which observed a close relationship between gating and shadowing or naming (Grosjean, 1980; Marslen-Wilson, 1987, 1990).

GENERAL DISCUSSION

Much of our knowledge about spoken word recognition has come from studies of monolingual English speakers. Researchers have generally assumed that their data, though restricted to a particular language, can be used to support a general theory of word recognition. While there may be good reasons to assume so, there are certainly other reasons to look beyond a monolingual word recognition model. A monolingual model cannot explain certain bilingual processing phenomena, because the phenomena may simply not exist in a monolingual situation (e.g., the interaction between language phonetics and phonotactic structure as found in this study). The present study, following Grosjean's pioneering work, takes a further step toward an explanation of bilingual spoken word recognition in a code-switch situation. The study provides new data on the problem, with two different experiments in a structurally different linguistic setting (i.e., Chinese and English). The gating experiment measures the amount of stimulus information needed for the correct identification of a CS word. The word-shadowing experiment measures the amount of processing time listeners need to pronounce a CS word. These experiments have provided converging evidence on the role of speaker output variations, phonotactic structures, base-language bias, and top-down contextual information.

However, the present study does not argue against the importance of monolingual research. In fact, in most cases it is both important and necessary to compare bilingual data with monolingual data, in order to interpret the data's theoretical implications. For example, comparison of bilingual and monolingual recognition times in Experiment 1 reveals that the amount of information required to identify an English word is similar for bilingual Chinese–English speakers as for monolingual English speakers. In a bilingual word recognition situation, listeners have to identify a CS word from a larger lexicon than they do in a monolingual situation. For example, given the initial two phonemes of a CV word which are compatible with both Chinese and English candidates, bilingual listeners are faced with the identification task from a much larger pool of lexical items. Indeed, this can sometimes cause identification problems at least initially, as shown by the early base-language effect in the word-candidate data in Experiment 1. However, with a bit more information downstream (about 200 ms of the word in context), bilingual listeners can quickly identify the target CS word, especially if the word is pronounced in the guest-language phonetics. On the average, they do not seem to need more time than English monolinguals in identifying English words under similar conditions.

The above comparison and the results derived therein enable us at least to arrive at two conclusions. First, the results argue against a language switch or monitor mechanism which says that bilinguals need more time to process code-switched materials than monolingual materials because switching (on and off) takes time (Macnamara, 1967; Obler & Albert, 1978). As both Sridhar and Sridhar (1980) and Grosjean (in press) have pointed out, the language-switch mechanism is less plausible than an activation mechanism that can simultaneously keep both languages on, probably to different degrees in different bilingual situations. Our data suggest that the strength of activation for the target word goes through a change from Chinese to English during an early identification process. Second, the results provide evidence for a parallel activation mechanism (e.g., Marslen-Wilson, 1987; McClelland & Elman, 1986) instead of a serial search mechanism (Forster, 1976, 1994). If word recognition is a serial search process, then the size of the lexicon should affect recognition: it should take more time to search through a (larger) bilingual lexical pool than a (smaller) monolingual one for the identification of the same word. In contrast, if word recognition is a parallel activation process, then the size of the lexicon should not matter: more lexical items in the pool need not require more identification times.

Results from Experiment 1 indicate that Chinese-English bilinguals, like English monolinguals, need about 200 ms to identify a CS word in a constraining context, but both groups need much more time (on the average 377 ms for bilinguals) to identify the same word in a neutral context. Prior context also significantly reduces the number of alternative lexical candidates in the recognition process, as shown in the word-candidate data. Results from Experiment 2 are consistent with those from Experiment 1. These data clearly speak to the effect of prior context on bilingual listeners' recognition of CS words. In particular, the result that a CS word can be recognized within about 200 ms in context suggests that context operates from early on to help bilingual listeners select the appropriate word. According to Marslen-Wilson (1987), in English there would be an average of 40 words still compatible with the available stimulus at 200 ms, when only the initial two phonemes are heard. Thus, it is hard to imagine how the listener could recognize a word within about 200 ms if they do not rely on contextual information from early on. In a bilingual situation, the problem may become even worse if context does not affect recognition early on, because the number of lexical candidates compatible with 200 ms of a word will be even larger (e.g., CV words whose initial phonemes are compatible with both languages). Only an interactive account in which context influ-

APPENDIX

Code-Switched Words Used in the Test Sentences

CC

break	plan
class	plug
clean	price
draft	print
drop	skip
flight	speech
friend	spend
group	stop

CV

bike	lock
book	sell
boss	sense
case	sit
cut	size
fail	solve
gift	take
list	talk

ences early stages of lexical access can accommodate these results.

In sum, parallel activation and interactive processes seem to offer the best account for the present data obtained in a bilingual word recognition situation. In order to recognize a CS word rapidly and successfully, bilingual listeners must have at their disposal a recognition mechanism that simultaneously integrates phonological, structural, and contextual information at various points in time. Current trends in psycholinguistics suggest that a mechanism that relies on the representational and processing properties of connectionist models may ultimately provide us with a satisfactory explanation of bilingual as well as monolingual spoken word recognition (Kawamoto, 1993; McClelland & Elman, 1986; Seidenberg & McClelland, 1989).

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