Using orthographic neighborhoods of interlexical nonwords to support an interactive-activation model of bilingual memory

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Abstract

Certain models of bilingual memory based on parallel, activation-driven self-terminating search through independent lexicons can reconcile both interlingual priming data (which seem to support an overlapping organization of bilingual memory) and homograph recognition data (which seem to favor a separate-access dual-lexicon approach). But the dual-lexicon model makes a prediction regarding recognition times for nonwords that is not supported by the data. The nonwords that violate this prediction are produced by changing a single letter of non-cognate interlexical homographs (words like *appoint* and *mince* that are words in both French and English, but have completely different meanings in each language), thereby producing regular nonwords in both languages (e.g., *appaint* and *monce*). These nonwords are then classified according to the comparative sizes of their orthographic neighborhoods in each language. An interactive-activation model, unlike the dual-lexicon model, can account for reaction times to these nonwords in a relatively straightforward manner. For this reason, it is argued that an interactive-activation model is the more appropriate of the two models of bilingual memory.

Introduction

The two opposing camps in the bilingual memory debate are, in essence, comprised of those who adhere to a "separate storage" dual-lexicon view and those who favor a more homogeneous memory organization, rather like monolingual memory, but with twice the number of words. Evidence from bilingual aphasia (Paradis, 1977; Albert & Obler, 1978, ch. 4;), where brain injury will cause the bilingual patient to completely lose one of his or her languages, would also seem to argue for modular language organization. In addition, "separate storage" dual-lexicon models have a certain intuitive appeal, in particular, because proficient bilinguals will report little inter-lexical interference. There have been a number of studies (Grosjean, 1989; Grosjean & Soares, 1986; Macnamara & Kushnir, 1971; Gerard & Scarborough, 1989; etc.) that seem to support a compartmentalized language-specific view of bilingual memory organization.

On the other hand, cross-lingual priming effects have been repeatedly demonstrated in the last twenty years and, in certain cases, interlingual priming effects may be as large as intralingual priming effects (Kolers, 1966; Meyer & Ruddy, 1974; Schwanenflugel & Rey, 1986; Beauvillain & Grainger, 1987; Beauvillain, 1992; Chen & Ng, 1989; De Groot & Nas, 1991; Hernandez, Bates, & Avila, 1995; etc.). Recently, Neumann, McCloskey, and Felio (1994) even claimed to have found conditions under which interlingual excitatory effects disappear but where interlingual inhibitory effects persist.

French & Ohnesorge (1995) proposed a model of bilingual memory based on parallel, self-terminating search through independent lexicons in which the search speed depends on the overall activation of the lexicon. This model did a good job of reconciling both interlingual priming data that would seem to support an overlapping bilingual memory organization (Beauvillain & Grainger, 1987) and homograph-recognition data that would seem to favor a separate-access dual-lexicon approach (specifically, Gerard & Scarborough, 1989).

In this article, however, we will present specific nonword reaction-time data that cannot be readily explained by the parallel-search dual-lexicon model. We will then show that these data are, in fact, compatible with an interactive-activation model. Because an interactive-activation model like those proposed by McClelland and Rumelhart (1981) and, more recently in the context of bilingual memory, by Grainger (1992), are also able to account for the homograph-recognition data in French & Ohnesorge (1995), we conclude that bilingual memory organization may actually turn out to be a lot like distributed, overlapping monolingual memory organization.

Interlexical homograph data support both types of bilingual memory models

Non-cognate interlexical homographs are words that have the same spelling but completely different meanings in two separate languages. For example, in French, words such as *fin* (= "end" in French), *pain* (= "bread" in French), *mince* (= "thin" in French), etc. The most interesting set of these words consists of "unbalanced" homographs, i.e., those with a high printed-word frequency in one language and a low frequency in the other (e.g., *fin* is a low-frequency word in English, high frequency in French).

Gerard & Scarborough (1989) made use of unbalanced non-cognate Spanish-English homographs to support the hypothesis that "lexical information is represented in language-specific lexicons and that word recognition requires searching the language-appropriate lexicon." Spanish-English bilinguals were asked to look word/nonword discrimination task in a single target language. Mixed into the single-language list of words were unbalanced English-Spanish non-cognate bilingual homographs. Their results show that word frequency in the currently active language — and not the overall frequency of usage in both languages — predicts homograph recognition time, thus lending support to the language-specific dual-lexicon hypothesis. So, even though *red* (= "net" in Spanish) is a high frequency word in English, Spanish-English bilinguals were no faster in the Spanish-only condition that Spanish monolinguals in recognizing it. The number of times the bilinguals had seen the item in English was of no help in its recognition in the All-Spanish condition. On the other hand, several studies using targets primed by non-cognate interlexical homographs (in particular, Beauvillain & Grainger (1987)) indicate that cross-lingual priming does occur. This would seem to contradict the view of independent language-specific lexicons supported by Gerard & Scarborough.

Parallel, activation-driven search through separate lexicons

French & Ohnesorge (1995) proposed a model that employed parallel search through independent lexicons with the search speed through each lexicon depending on the overall activation of that lexicon. This model seemed to reconcile the apparently contradictory findings of Beauvillain & Grainger and Gerard & Scarborough.

When only a single lexicon was active (for example, when bilinguals saw only words in one language), as in Gerard & Scarborough (1989), this model predicted word recognition reaction times that would correspond to those of a monolingual since the search speed through the inactive lexicon would be extremely slow, slow enough that the version of the bilingual homograph stored in the inactive lexicon would never be reached. The search speed would through the active lexicon would therefore correspond roughly to the monolingual search speed through an equivalent lexicon.

The cross-lingual priming results obtained by Beauvillain & Grainger (1987) can also be accounted for by this type of model. In their experiment all prime words were in French and all target words were in English. The French primes were presented for 100 ms. Since response times to the English words were approximately 600 ms., we can conclude that, on average, the subjects saw English words six times as long as French words. As a result, it is reasonable to conclude that the English lexicon would be considerably more active than the French lexicon. Consequently, when subjects saw the prime word "four" (= "oven" in French), it is quite possible that it was frequently perceived not as a French word, but rather as an English word, due to the fact that the English lexicon was so much more active than the French lexicon. It is therefore not surprising that there would have been some priming of the English target "five," which is what the authors reported.

In short, the dual-lexicon parallel-search model does a remarkably good job at accounting for the apparently contradictory data of Gerard & Scarborough (1989) and Beauvillain & Grainger (1987). French & Ohnesorge (1995) also showed that this model correctly predicted reaction-time shifts for recognition times of interlexical homographs when moving from a monolingual to a mixed-language condition. Unfortunately, this model cannot account for certain *nonword* reaction-time data. For this reason, we introduce interactive-activation models. First, we will claim that these models are functionally equivalent, if intuitively less appealing, to the dual-lexicon parallel-search model for word recognition. We will then go on to present the problematic nonword recognition data and show how an interactive-activation model can handle this data.

The results reported in this paper are based on preveiously unexamined data from French & Ohnesorge (1995). This new study was undertaken because of work reported in Grainger (1992) and Grainger and Dijkstra (1992) on the use of orthographic neighborhoods (Coltheart, 1977) to study bilingual memory organization. Using an orthographic-neighborhood technique similar to the one employed by Grainger & Dijkstra, we examined a set of non-cognate interlexical nonwords (nonwords created from homographs that produced regular nonwords in both languages) contained in our original set of stimuli.

We had anticipated a straightforward confirmation of the prediction our parallel-search dual-lexicon model made with regard to nonwords — namely, that these nonwords would be recognized as not being a word either in French or in English faster in the Mixed Condition (i.e., where both lexicons are active) than in the All-French Condition (i.e., where only the French lexicon is active). This prediction was based on the fact that in order to recognize an item as a nonword (i.e., not a word in either language), both lexicons have to be "exhaustively" searched. This search, even though it is a parallel search of the lexicons, would conclude more quickly — thus allowing the determination that an item is a nonword — when both lexicons were active (Mixed condition), than when only one was (All-French condition).

To our surprise, we found that certain types of nonwords were actually recognized as nonwords *more slowly* in the Mixed Condition than in the All-French Condition. After attempting to fit these results into the framework of a parallel-search, dual-lexicon model, we concluded that:

- distributed interactive-activation models give a better account of this data than the independent-lexicon model;
- interactive-activation models can also account for the homograph-recognition data that the parallel-search dual-lexicon model handled so well.

In what follows we will concentrate on the former point because the nonword reaction time data is the key to distinguishing these two types of models. A parallel-search dual-lexicon model cannot explain nonword reaction time data; an interactive-activation model can. Space limitations do not allow us to explain how interactive-activation models can also account for the homograph reaction-time data presented in French & Ohnesorge (1995).

Experimental design

Participants

The participants were 48 bilingual males and females recruited from the University of Wisconsin (Madison, WI) and the surrounding community. Virtually all were in daily contact with both French and English and judged themselves highly fluent in both French and English. The pool was made up of professors and graduate students in the French department, translators, and native French speakers having lived for many years in the US, etc. Twenty-five of the subjects were native French speakers. The participants were randomly assigned to the two conditions of the experiment.

Stimuli

The critical stimuli consisted of a set of 27 non-cognate interlexical nonwords. These nonwords were produced by changing a single letter of a non-cognate interlexical homograph (i.e., words like *appoint*, *legs*, *mince*, etc., all of which have distinct meanings in French and English). This produced regular nonwords in both French and English. For example, starting with the non-cognate interlexical homograph *mince* (= "thin" in French), we produce the non-cognate nonword *monce* by changing the "i" in *mince* to an "o". This gives a regular nonword in both French and English.

Procedure

The experiment consisted of two conditions, an All-French condition in which participants saw only French words/nonwords, and a Mixed condition in which they saw half French and half English words/nonwords. In the condition in which participants saw words only in French, the instructions were also orally explained in French. In the condition in which subjects saw half French and half English items during the test procedure, the instructions were first explained in English. Subsequently, the same instructions in French were then read by the participants on the computer screen.

All-French Condition Participants did the experiment individually in 45-minute sessions in which they responded to 450 experimental trials. The experiment was run on PsyScope (Cohen *et al*, 1993) on a Power Macintosh computer. Participants were seated approximately 20" from the computer monitor. The instructions indicated that they would see letter strings and were to classify them as words (if they were real words in French or in English) or nonwords. Included in the list of lexical items were the critical non-cognate nonwords. Reaction time to these nonwords was the critical dependent variable. Of particular interest were "unbalanced nonwords" that had a large orthographic neighborhood in one language and a small orthographic neighborhood in the other language. After reading the instructions, the participants initiated a block of 40 practice trials. Upon completion of the practice block, they began the experimental trials. On each trial a letter string was presented and remained on the screen until a response was made. After a 500 ms interval the next stimulus was presented. Feedback, in the form of a beep, indicated when a word/nonword had been misclassified. Altogether, participants responded to a total of 450 letter strings: 180 French words, 180 French-based nonwords, 45 regular French/English nonwords and 45 homographs.

Mixed Condition Identical to the All-French condition, except that the "filler" stimuli consisted of an equal mixture of French and English words and nonwords. The word/nonword lexical decision task was the same as in the All-French condition.

Results

French & Ohnesorge (1995) showed that an activation-driven parallel-search dual-lexicon model could account for data reported by Gerard & Scarborough (1989), which seemed to favor a separate-access dual-lexicon model, and Beauvillain & Grainger (1987), which seemed to support an overlapping, distributed model. But a key prediction of their parallel-search dual-lexicon model is that nonwords will be rejected faster in the Mixed Condition than in the All-French Condition. This turned out not to be the case. In what follows we discuss this key prediction and explain how it can be accounted for by an interactive-activation model similar to the Grainger's (1992) Bilingual Interactive Activation (BIA) model, itself based on the

McClelland and Rumelhart's (1981) Interactive-Activation model.

The key prediction for nonword data

The dual-lexicon parallel-search model makes a clear prediction for all nonwords: reaction times will be faster in the Mixed condition than in the All-French condition. This is because in the Mixed condition both lexicons are fully active and are therefore both being searched in parallel at full speed. By contrast, in the All-French condition, the search speed through the English lexicon is less than it would be in the Mixed condition (because the English lexicon is less active than in the Mixed condition since the participant has seen only French words during the experiment). Therefore, it should take less time to recognize a nonword as being neither a real word in French nor in English in the Mixed condition. We will see that this prediction is not supported by the data.

Non-cognate interlexical nonwords

The stimuli that we will examine are nonwords produced by changing a single letter of a non-cognate interlexical homographs, thereby producing regular nonwords in both French and English. For example, starting with the non-cognate interlexical homograph *legs* (= "legacy" in French), the non-cognate nonword *ligs* is produced by changing the "e" in *legs* to an "i". This gives a regular nonword in both French and English.

Non-cognate bilingual nonwords can be classified by means of an orthographic neighborhood technique similar to the one used by Coltheart *et al* (1977) and Grainger & Dijkstra (1992). Words are said to be orthographic neighbors if all of their letters but one match up. (Thus, "mare" is an orthographic neighbor of "more" since the two words match up except at their second position.) The nonwords are classified as High-English-Neighborhood/ Low-French-Neighborhood (HEN/LFN) or Low-English-Neighborhood/High-French-Neighborhood (LEN/HFN), according to the number and word-frequency of their respective orthographic neighbors in the two languages. Thus *ligs* is a High-English-Neighborhood/Low-French-Neighborhood nonword because it has more English neighbors than French neighbors. Its English neighborhood consists of {*digs, figs, jigs, pigs, rigs, wigs, lags, logs, lugs, lugs, lids, lies, lips*} and its French neighborhood is {*lits, lige*}. Incorporating frequency information allows us to classify nonwords such as *appaint* — derived from the interlexical homograph *appoint* (= "additional contribution" in French) — as having a High-English-Neighborhood/Low-French-Neighborhood, even though *appaint* has, strictly speaking, no French-only or English-only neighbors; its only neighbor is the homograph *appoint*. It is classified as HEN/LFN because *appoint* has a considerably higher frequency in English than in French. All nonwords had at least four letters.

(This is certainly not the only way that neighborhoods could have been defined. For example, another technique might have determined neighborhoods on the basis of letter clusters. So for example, all words sharing the ending "tion" or beginning with "st" might have been considered to be part of a neighborhood. We felt, however, that for our purposes the essence of orthographic proximity was adequately captured by Coltheart's (1977) technique.)

An analysis of the HEN/LFN and LEN/HFN non-cognate nonwords produces a striking result (Fig. 1). When going from the All-French to the Mixed Condition, the time required to recognize High-English-Neighborhood/Low-French-Neighborhood (HEN/LFN) nonwords as being nonwords actually *increases* by 62 ms from 805 to 867 ms. (Interaction effect of Neighborhood-Type(HEN/LFN, LEN/HFN) X Language-Condition(All-French, Mixed): over subjects: $F(1,45)=6.3$, $p=0.015$; marginally significant over items: $F(1,24)=3.25$, $p=0.08$. The derivative simple effect of Condition on HEN/LFN nonwords: Tukey HSD(0.01) = 60.2 ms.) For Low-English-Neighborhood/High-French-Neighborhood nonwords there is no significant reaction time difference between the two conditions (853 vs. 850 ms.)

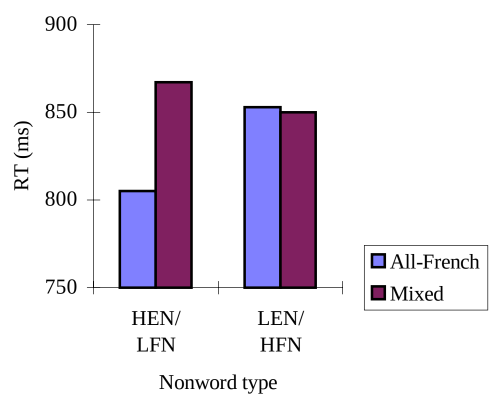

Figure 1. Reaction times to reject non-cognate bilingual nonwords according to the type of neighborhood (HEN/LFN or LEN/HFN) of the nonwords.

Interactive-activation model explanation of non-cognate nonword reaction time data

Even though the dual-lexicon parallel-search model accurately predicts shifts in reaction time from the All-French to the Mixed condition for non-cognate interlexical homographs (French & Ohnesorge, 1995), Figure 1 shows that it gives a highly inaccurate prediction for the shifts that occur for non-cognate interlexical nonwords.

To understand why an interactive-activation model is able to provide a good explanation for the observed shifts in HEN/LFN and LEN/HFN non-cognate nonwords, let us start with the following observation: the more closely a nonword resembles one or many real words, the longer people will take to recognize it as a nonword. This, of course, is why *doned* looks more like a real word than, say, *ptunx*, even though, technically speaking both are regular nonwords in English (even though *pt* and *nx* are rare bigrams in English, they are certainly legal; what child does not know about *pterodactyls* or *sphinxes*?). There are many real words that look a lot like *doned* (e.g., *boned, toned, stoned, cloned, dined,* to say nothing of the fact that the word contains *done*, etc.), while there is almost nothing whatsoever that looks like *ptunx*. In short, to recognize *doned* as a nonword, we must somehow overcome the competition from real words that are similar to it. And this is why it will generally take longer to realize that *doned* is a nonword than *ptunx*. This observation forms the basis of the interactive-activation model explanation of the reaction times to the HEN/LFN and LEN/HFN non-cognate nonwords in Figure 1.

Let us take a closer look at nonword recognition for the particular case of High-English-Neighborhood/Low-French-Neighborhood (HEN/LFN) nonwords. First, consider the All-French condition (Figure 2a). For the purposes of our explanation, we will consider the nonword *ligs*. As indicated above, *ligs* has a large English neighborhood and a small French neighborhood. In the All-French condition, l-i-g-s will send activation to its French-word neighbors *lits* (= "beds") and *lige* (= "liege", a very low frequency word). These words will also receive mutual reinforcement from the activation in the French lexical system (base activation), since this lexicon, and only this lexicon, is active in the All-French condition. At the same time, l-i-g-s will send activation to its English-word neighbors *digs*, *jigs*, *lids*, etc. However, these English neighbors, while they will be somewhat active (since subjects are told to reply "Nonword" if the item they see is not a word in either French *or in English*), they will not be

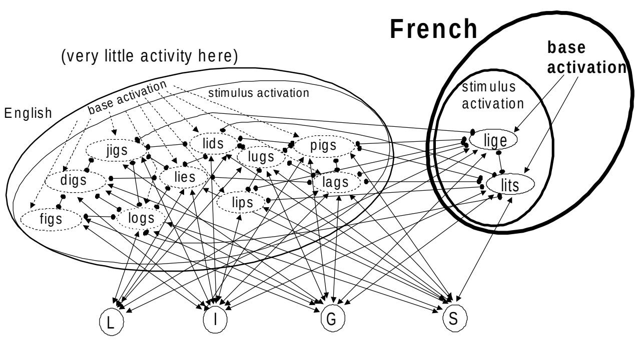

Figure 2a. Non-cognate interlexical nonword recognition in the All-French condition. The words in the English orthographic neighborhood are not as active as in the Mixed Condition.

as active as they would be if the English lexical system were highly active, as in the Mixed condition. The more numerous and the more highly active the real-word neighbors of a nonword are, the longer it will take to decide — just as in the case of *doned* and *ptunx* — that the item is, in fact, a nonword. In the Mixed condition (Figure 2b), all of the English neighbors will be considerably more active.

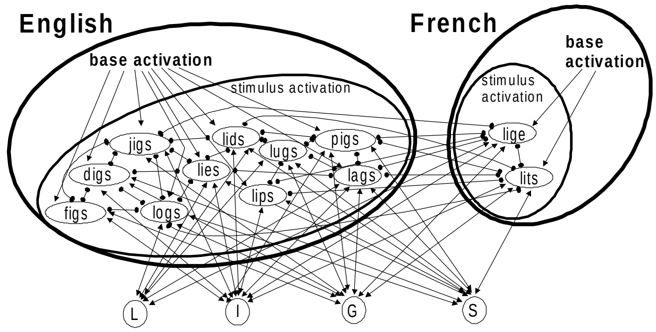

Figure 2b. Non-cognate interlexical nonword recognition in the Mixed condition. The words in the English orthographic neighborhood are considerably more active that in the All-French condition. This additional activation must be overcome before the HEN/LFN nonword "LIGS" can be determined to be a nonword. This results in the longer reaction times in the Mixed Condition.

In other words, in the Mixed condition, a greater number of words will be somewhat nearer perceptual threshold than in the All-French condition, producing a stronger feeling of "knowing" the nonword. Until all of the active real-word "competitors" can be inhibited (or return to baseline activation), one will not judge the item to be a nonword. Since, in the Mixed condition, there are a greater number of active competitors, the interactive-activation model would predict that a nonword decision for High-English-Neighborhood/Low-French-Neighborhood nonwords will take longer in the Mixed condition than in the All-French condition. This corresponds to the data.

A similar argument can be used to explain why reaction times to Low-English-Neighborhood/High-French-Neighborhood nonwords show little change between the two conditions.

Conclusion

French & Ohnesorge (1995) showed how a simple dual-lexicon model using differentially active, parallel search could be used to account for homograph recognition-time data in bilinguals. This model seemed, in addition, to reconcile an apparent conflict between the results of two well known experiments (Gerard & Scarborough, 1989 and Beauvillain & Grainger, 1987). We claim, but for reasons of limited space do not show, that an interactive-activation model can also account for this homograph recognition data. But most importantly, in this paper we uncover what seems to be a major flaw in independent-access dual-lexicon models — namely, they make a clearly inaccurate prediction regarding reaction times for a class of non-cognate interlexical nonwords. We then show how an interactive-activation model could explain the nonword data that the dual-lexicon model could not. In conclusion, it is reasonable to assume, in light of these arguments, that an interactive-activation model is likely to be a better model of bilingual memory than the intuitively more appealing dual-lexicon parallel-search model.

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