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Recognition of Cognates and Interlingual Homographs: The Neglected Role of Phonology

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In two experiments Dutch–English bilinguals were tested with English words varying in their degree of orthographic, phonological, and semantic overlap with Dutch words. Thus, an English word target could be spelled the same as a Dutch word and/or could be a near-homophone of a Dutch word. Whether such form similarity was accompanied with semantic identity (translation equivalence) was also varied. In a progressive demasking task and a visual lexical decision task very similar results were obtained. Both tasks showed facilitatory effects of cross-linguistic orthographic and semantic similarity on response latencies to target words, but inhibitory effects of phonological overlap. A third control experiment involving English lexical decision with monolinguals indicated that these results were not due to specific characteristics of the stimulus material. The results are interpreted within an interactive activation model for monolingual and bilingual word recognition (the Bilingual Interactive Activation model) expanded with a phonological and a semantic component. © 1999 Academic Press

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Shakespeare (1564–1616) was aware that words may sound similar in different languages, even when their meanings are very different. In Henry V (act 3, scene 4) he used his wonderful writing skills to turn this observation to his benefit in the following way. Katherina, the French princess who is destined to marry Henry V, is taught English by Alice, her maid. When she has learned a number of words, Katherina asks how to say "pied" and "robe" in English. Alice tells her "foot" and "gown." When Katherina repeats these words with a French accent, they sound like obscene French words. Katherina is shocked and exclaims that these English words sound "mauvais, corruptible, gros, et impudique" ("bad, depraved, rude, and unchaste"). She adds that she would not use these words in the vicinity of French noblemen; but then hesitates before admitting that they are necessary after all—a remark that pleases the audience a great deal.

For researchers investigating word recognition, such similarities of words within and across languages are also interesting because form-similar or form-identical words provide a real challenge to the recognition system. If word

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recognition involves the retrieval of semantic information on the basis of a word's phonological or orthographic form, word forms that are associated with multiple meanings require the selection of one of these from the different possibilities. For instance, coming across the letter string BAT while reading a text, one has to decide whether that string refers to a kind of stick or to a fluttering mammal. As shown by the introductory example, the same sort of problem arises in the comprehension of spoken language, e.g., when one hears a phonological form like /bæt/.

Word forms may also be shared by words of different languages. For instance, in the case of *interlingual homographs,* words in different languages share the same orthographic form. The English word ANGEL, for example, is spelled just like a Dutch word meaning "sting." Such words are also called *false friends,* for they look similar but have very different meanings. In addition to their form, words of different languages may share (some of) their meaning(s), i.e., they may be translation equivalents. Those interlingual homographs that not only share their orthographic form but their semantics as well are termed *cognates.* An example is the word LIP with approximately the same meaning(s) in English and Dutch. To avoid confusion, the term homograph will be restricted in this article to cases of form identity without meaning overlap, thus excluding cognates. The latter term will be used for cases of both form and semantic overlap.

Given this overlap in form and—in the case of cognates—meaning across languages, a study of the recognition of interlingually ambiguous words may reveal how the bilingual lexicon is accessed and organized. For instance, if access to information stored in the bilingual's lexicon is selective with respect to language, only the English reading of a word like ANGEL would be accessed when a Dutch–English bilingual reads this word in an English text. Consequently, the stored knowledge about the Dutch word form would not affect recognition of the English target reading. However, if lexical access is nonselective with respect to language, an effect of the Dutch reading of the word form would be likely to occur.

To address this issue of language-selective versus -nonselective lexical access, many studies in the bilingual domain have investigated the processing of interlingual homographs and cognates in bilinguals (for overviews see Grainger, 1993, or Keatley, 1992). Several recent empirical studies support the theoretical position that the bilingual language processing system is basically nonselective in nature, but that it may produce more selective results under particular experimental circumstances dependent on task demands and language intermixing (Beauvillain & Grainger, 1987; Caramazza & Brones, 1979; Cristoffanini, Kirsner, & Milech, 1986; Dijkstra, Timmermans, & Schriefers, submitted; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998).

The main factor that has been manipulated in these studies is the relative word frequency of the two readings of the homographs or cognates in the two languages at hand (e.g., Gerard & Scarborough, 1989; De Groot, Delmaar, & Lupker, in press; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Dijkstra, Timmermans, & Schriefers, submitted). Although conflicting results do exist, it has repeatedly been found that interlingual homographs and cognates show large cross-language effects (i.e., faster or slower response times (RTs) relative to nonambiguous controls) when they have a relatively low printed frequency in the target language and a higher frequency in the nontarget language. The largest effects have been obtained for items with a low frequency in the target language and a high frequency in the other language.

THE NEGLECTED ROLE OF PHONOLOGY

Studies focusing on effects of relative frequency in interlingual homograph recognition have paid little attention to another important dimension of the stimulus material that is a likely determinant of cross-language effects: the cross-language similarity of the items in phonology. The amount of phonological overlap present in the cognates and homographs used in experiments varies considerably. Several investigators merely state explicitly that their interlingual homographs (e.g., Beauvillain & Grainger, 1987) or cognates (e.g., Cristoffanini et al., 1986) differ in their phonology across the bilingual's two languages. In their experiments they make no attempt to systematically control for interlingual homophony, and there is no guarantee that this variable was not confounded with interlingual homography or cognateness or even both. Some of the conflicting evidence on cognates and homographs across studies may be due to such uncontrolled confounding with interlingual homophony.

This neglect is especially noticeable since research in the monolingual domain has shown that phonology plays a considerable role in visual word recognition (see Frost, 1998, for an overview). Evidence has been obtained from research with masked pseudohomophone priming (e.g., Ferrand & Grainger, 1994; Perfetti & Bell, 1991), semantic categorization of homophones (e.g., Van Orden, 1987; Van Orden, Johnston, & Hale, 1988), letter search in pseudohomophone stimuli (Ziegler & Jacobs, 1995), and many other paradigms.

There has been little work on the role of phonology in visual word recognition in bilinguals. The few bilingual studies that are available indicate that phonological similarity across languages also plays a role in the bilingual domain. The majority of these studies have involved interlingual pseudohomophones (Brysbaert, Van Dyck, & Van de Poel, 1999; Nas, 1983) and homophonic noncognates or cognates (Doctor & Klein, 1992; Brysbaert et al., 1999; Gollan, Forster, & Frost, 1997; Lam, Perfetti, & Bell, 1991; Tzelgov, Henik, & Leiser, 1990; Tzelgov, Henik, Sneg, & Baruch, 1996). These studies have addressed two different but related questions: (1) Is performance on a target stimulus influenced by the phonological similarity between that stimulus and a word from the nontarget language? (2) Are nontarget language spelling-to-sound rules automatically applied during target stimulus processing? The present study is mainly concerned with the first question, and we consider past research especially from the perspective of this issue.

Nas (1983) asked Dutch–English participants to perform an English lexical decision experiment (Experiment 2) in which half of the nonwords were cross-language pseudohomophones. These were constructed by changing the spelling of a Dutch word in such a way that their orthographic appearance was English, but their pronunciation according to English spelling-to-sound conversion rules was still the same as the original Dutch word. For instance, the pseudohomophone SNAY was derived from the Dutch word SNEE meaning "cut." Clearly, SNAY differs from SNEE in its orthography—moreover, to a Dutch speaker it does not look like Dutch but like English—but according to English spelling-to-sound correspondences SNAY sounds very much like the Dutch word, which is pronounced [snay]. The Dutch–English bilingual participants were slower in rejecting the cross-language pseudohomophones than the regular nonwords (such as PRUSK, which is not homophonic with a Dutch word or an English word) and made more errors on them. This result indicates that internal representations of Dutch words are activated during an English lexical decision task, supporting the hypothesis of language nonselective lexical access. Moreover, access to the internal lexicon of a bilingual seems to proceed at least in part via nonselective phonological mediation.

Further evidence for effects of cross-language phonological similarity in bilingual word recognition was provided by Doctor and Klein (1992). In their study, English–Afrikaans bilinguals had to decide whether letter strings were words in either of their two languages (generalized lexical decision task). As in a standard (monolingual) lexical decision task, half of the presented letter strings were words and half were nonwords. One quarter of the words were interlingual homophones (e.g., LAKE–LYK), while the remaining items were interlingual homographs (e.g., KIND) and words that were exclusive to one of the two languages. Half of the nonwords were pseudohomophones in English (e.g., GRONE) or in Afrikaans (e.g., FLOEI). With respect to the present investigation, the most interesting result of this study was the inhibitory effect of interlingual homophony. The English–Afrikaans homophones were responded to more slowly and less accurately than the interlingual homographs. In fact, the homophones were responded to at about the same speed and accuracy as the nonwords in the experiment. Doctor and Klein (1992) interpreted these results by assuming that lexical access proceeds in parallel to the English and Afrikaans orthographic lexicons, while phonological representations are activated simultaneously by a language nonselective grapheme–phoneme translation process. Next, the phonological representation of an interlingual homophone in the bilingual lexicon is found to be associated with two orthographic entries rather than one. This detection of a "mismatch" needs to be resolved, resulting in slower responses to interlingual homophones relative to monolingual control items.

Indirect evidence supporting a role of phonological factors in bilingual processing was obtained in a masked translation priming study by Gollan et al. (1997). In three experiments, Hebrew–English or English–Hebrew bilinguals made a lexical decision on Hebrew or English target words that were preceded by briefly presented prime words from the same or the other language. Cross-language prime–target pairs consisted of cognate or noncognate translation equivalents or unrelated items. The Hebrew–English cognate items overlapped in phonological form and meaning, but not in orthographic form because the Hebrew script bears no visual relationship to the Roman script used in English. Relative to noncognate item pairs, enhanced cross-language priming effects were found for the Hebrew–English cognate item pairs when the target words were preceded by primes from the dominant language of the bilingual participants, but not when the primes were from their nondominant language. According to the authors, the presence of such enhanced cross-language effects for cognate items that do not share their orthography is evidence that phonological similarity must play a mediating role in these experiments. The asymmetric nature of the cognate effects obtained with different scripts may be attributed to an overreliance on phonology in reading in the second language.

A number of studies indicate that when bilinguals process target words in one language they apply not only the spelling-to-sound conversion rules of that language but also those of their other language at the same time. Tzelgov et al. (1996) tested Hebrew–English bilinguals in a Stroop color naming task with "cross-script homophones," items that sound like a color word in the target language when pronounced according to the spelling rules of the nontarget language. An example is the English-written letter string "kahol" that sounds like the Hebrew color name for "blue" when pronounced according to English spelling rules. For items like this that were presented in an incongruent color (e.g., "kahol" in red ink), the common Stroop interference effect was found. This result supports the automatic application of sublexical grapheme-to-phoneme conversion rules of the nontarget language to the input letter string during the retrieval of the target language color name for this string. Because these stimuli printed in Roman script cannot be assigned a pronunciation using Hebrew spelling-to-sound correspondences, the data indicate that nontarget language spelling-to-sound correspondence rules cannot be suppressed even when they hinder performance.

More direct evidence supporting the parallel application of spelling-to-sound rules of two languages to stimulus input has recently been provided by Brysbaert et al. (1999). These authors observed an interlingual phonological effect in a masked priming paradigm. Dutch–French bilinguals and French monolinguals identified briefly presented French target items preceded by briefly presented and masked prime words or nonwords. In the first experiment, the primes were French nonwords or Dutch words. French nonword primes belonged to three types. They were pseudohomophones created by changing one letter of the target word (e.g., "fain–FAIM"), nonhomophonic controls with the same letters in common with the target ("faic–FAIM"), or pseudohomophonic nonwords with only one letter in common with the target word ("fint–FAIM"). If the prime was a Dutch word, it was either homophonic to the French target ("paar–PART"), a graphemic control (“paal–PART”), or unrelated to the target (“hoog–PART”).

For the French prime–French target stimuli, the bilinguals identified fewer target words than the monolinguals, but the two groups displayed similar orthographic and phonological priming effects for the three types of nonwords. For the Dutch prime–French target stimuli, the effects of orthographic prime–target overlap were also comparable across the two groups of participants. However, with respect to phonological overlap a different pattern emerged for bilinguals and monolinguals. Significant interlingual phonological priming effects were observed for the bilingual but not for the monolingual participants.

In a second experiment, the effects were replicated with Dutch homophonic and graphemic control nonwords as primes. A Dutch homophonic nonword is a sequence of letters that is a word in neither Dutch nor French and that according to Dutch—but not French—pronunciation rules sounds like a French target word. An example is “soer,” which in Dutch would be pronounced very similar to the French word SOURD. Even though the bilingual participants were unable to identify the prime stimuli and although they were unaware of the bilingual nature of the task, they appeared to automatically apply the letter-to-sound conversion rules of both their languages.

This short review clearly shows that the bilingual recognition of words from the same or different scripts is affected by cross-language phonological similarity. However, most bilingual studies ascribe a major importance to cross-linguistic orthographic similarity (interlingual homographs) and semantic equivalence (translation equivalents and cognates) but ignore the effects of phonological overlap. Thus, an important goal of study must be to assess the precise contribution of phonological codes to the bilingual word recognition process and to determine their interaction with orthographic and semantic codes.

In this article we attempt to disentangle the effects of the different types of overlap on the word recognition of Dutch–English bilinguals by introducing a number of systematically controlled types of false friends and cognates. In total, we defined six different test-word conditions by orthogonally and bimodally varying semantic, orthographic, and phonological overlap between English and Dutch lexical representations. Three of these conditions involved cognates that were both homographic and homophonic across languages, only homographic, or only homophonic. The other three conditions were similar types of false friends. All test words in the six conditions are given in the Appendix. The resulting test word categories can be referred to by the following abbreviations: SOP, SO, SP, OP, O, and P words. The capitals indicate on which dimension(s) the English test words are similar/identical to Dutch words: “S” stands for similar semantics, “O” for identical orthography, and “P” stands for similar phonology. Thus, the abbreviation “SOP” refers to the homophonic cognates with identical orthographies (e.g., HOTEL–HOTEL), while “P” refers to nonhomographic homophonic false friends (e.g., COW–KOU, meaning COLD in Dutch).

All examples of cognates and homographs have identical orthographic word forms. Whereas in most studies cognates are defined as translation equivalents with completely identical orthographies (e.g., FILM–FILM), some researchers apply deviating definitions. For instance, in the terminology of De Groot and Nas (1991), English–Dutch word pairs like HEIGHT–HOOGTE and POLICE–POLITIE are cognates. The term “semi-cognate,” coined by De Bot, Cox, Ralston, Schaufeli, and Weltens (1995), would probably be more appropriate here, since, apart from the existing sound differences, these Dutch and English translation equivalents obviously differ with respect to their spelling (accordingly, De Groot and Nas define cognates as translation equivalents that are *similar* in their sound and spelling).

The variation in the definitions of cognates and (to some extent) homographs complicates the comparison of different experimental results. Furthermore, it would seem to be a good research strategy to start investigating *identical cognates* and *identical homographs* because it is currently not clear to what extent form differences may affect competition among lexical candidates. Available experimental and simulation work involving bilingual neighborhood effects by Van Heuven et al. (1998) indicates that even small differences in word form have considerable effects on lexical processing, both in terms of lexical competitor sets and processing time. Form-identical cognates and homographs, however, have identical sets of lexical competitors within and between languages.

The incorporation of the six maximally divergent conditions mentioned above in the experiments allows us to test a number of hypotheses. First, any effects of similarity with a nontarget language word on the recognition of that target word can be taken as evidence against a language-selective access hypothesis. Second, if overlap on all three manipulated dimensions (orthography, phonology, and semantics) exerts a comparable and facilitatory effect on target recognition, the RTs in the different experimental conditions will be ordered as follows, from fast to slow: SOP, SO/SP/OP, O/P, control items. This prediction is based on the assumption that similarity on more dimensions would lead to larger facilitation effects and on the observation that empirical studies have generally found facilitation effects for cognates that are larger than for interlingual homographs (e.g., Dijkstra, Van Jaarsveld, & Ten Brinke, 1998). The larger effect for cognates would be due to the cross-linguistic semantic overlap, which is absent in interlingual homographs.

We tested these six word conditions on Dutch–English bilinguals in two experiments involving different paradigms. In the first experiment we used the progressive demasking task in which the presentation of a target word is alternated with that of a mask. During this process of alternation, the target presentation time increases while that of the mask decreases. The participant's task is to push a button as soon as the target word is identified. Presentation conditions are adjusted such that the average RT, measured from the onset of the alternation process, falls between 1 and 2 s. Compared to other paradigms (such as lexical decision), progressive demasking reduces the rate of presenting the sensory information to the participant, thus effectively slowing the target identification process. Prior work using progressive demasking and related techniques both monolingually and bilingually has demonstrated the sensitivity of the paradigm to various aspects of lexical processing (Carreiras, Perrea, & Grainger, 1997; Grainger & Segui, 1990; Schreuder & Baayen, 1997; Snodgrass & Mintzer, 1993; Van Heuven et al., 1998). In the second and third experiment we used the same stimulus material in a standard English lexical decision task, which required the inclusion of nonwords in the stimulus list. The last two experiments only differed in terms of their participants, who were Dutch–English bilinguals in the second experiment and English monolinguals in the third experiment.

EXPERIMENT 1: PROGRESSIVE DEMASKING WITH DUTCH–ENGLISH BILINGUALS

Method

Participants. Forty students of the University of Nijmegen with normal or corrected-to-normal vision participated in the experiment for course credit. All students were native speakers of Dutch who had learned English as a foreign language at school for at least 6 years and used English regularly during their study.

Stimuli. A list of English three-, four-, and five-letter words was extracted from the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993). Only nouns and adjectives with a printed-lemma frequency of at least two occurrences per million (o.p.m.) were included. Next, English items were selected that were as similar as possible to Dutch words with respect to their orthography, phonology, and/or semantics. A general selection criterion was that the test words had to be similar to just one, or mainly one, Dutch word. In other words, a test word was allowed to have only one strong Dutch competitor word. For example, BEER was not selected: not only does it have the same orthographic form as the Dutch word BEER, meaning BEAR, it also is written and pronounced very similarly to the Dutch word BIER, meaning BEER. In addition, only words were se-

TABLE 1

Mean English and Dutch Word Frequency (in Occurrences per Million), Length (in Number of Letters) and Semantic, Orthographic, and Phonological Subjective Similarity Scores of Test Words and Control Words in the Different Test Conditions

	Test words						Control words	
Word type	English frequency	Dutch frequency	Word length	Semantic similarity	Orthographic similarity	Phonological similarity	English frequency	Word length
SOP	41.3	32.3	4.0	6.3	7.0	6.1	41.5	4.0
SO	43.0	27.9	4.2	6.7	7.0	2.9	43.0	4.2
SP	42.5	27.2	4.2	6.2	3.3	5.7	42.0	4.2
OP	40.2	27.9	3.9	2.1	7.0	6.0	40.3	3.9
O	40.2	27.4	4.2	1.6	7.0	2.6	40.4	4.1
P	41.7	29.1	3.9	1.2	2.8	6.0	41.9	3.9

lected that were expected to be known to the intended population of Dutch–English bilingual participants.

For each of the six different conditions (SOP, SO, SP, OP, O, and P) 15 English test words were selected. All test words are given in the Appendix. The SOP, SO, and SP words and their Dutch competitor words were translation equivalents. The OP, O, and P words, however, had different meanings from their Dutch competitors. The orthographic forms of the SOP, SO, OP, and O words were identical to those of their Dutch competitors. The cross-language similarity with respect to orthography of the SP and P words was kept as low as possible. Finally, while the cross-language similarity with respect to phonological overlap was very high for words of the SOP, SP, OP, and P conditions, it was as low as possible for words of the SO and O conditions.

To obtain a measure of the subjective cross-language similarity of the test items, we asked 12 participants from the same population to rate the orthographic, phonological, and semantic overlap of each of the 90 English items with their major Dutch competitor word on a scale from 1 (no similarity or overlap) to 7 (perfect similarity or overlap). English items unknown to the participants had to be indicated and received a semantic score of 1 (no perceived overlap). Each partipant saw all test items three times in different blocks. Each block consisted of English–Dutch item pairs in a unique pseudorandomized order with maximally four item-pairs from one stimulus condition in a row. The order in which the items were scored on the three dimensions was counterbalanced over participants. The generalizability coefficient (Cronbach's alpha) across raters was 0.98 for the semantic scores on the 90 item-pairs, 0.99 for the orthographic scores, and 0.97 for the phonological scores. The resulting mean scores across participants for all Word Types on all three dimensions are given in Table 1. As can be seen, the subjective similarity scores confirm that item selection was in correspondence with the criteria distinguishing the different test conditions.

The English test items in the six conditions were on average of the same length (number of letters) and were matched with respect to English word frequency and Dutch competitor word frequency. Each test word was assigned a control word that was matched in English frequency, length and, where possible, consonant–vowel structure. Table 1 shows the word frequencies and length of the test and control items in the different conditions. Only English words that deviated considerably in their spellings and pronunciations from any Dutch word were used as controls.

Procedure. Participants were tested individually in a soundproof room. Presentation of the visual stimuli and recording of RTs was controlled by an Apple Macintosh Quadra computer. The experimentation software was devel-

TABLE 2

Mean Response Times (RT, in Milliseconds), Standard Errors (SE), and Error Percentages (Error %) for All Test Conditions and Their Matched Controls in Experiment 1

	Test words			Control Words				
Word type	RT	SE	Error %	RT	SE	Error %	RT effect	Error effect
SOP	1714	31	1.7	1760	34	3.9	−46**	−2.2*
SO	1702	34	1.3	1742	33	2.7	−40*	−1.4
SP	1741	32	2.4	1766	35	5.5	−25	−3.1*
OP	1761	33	2.0	1722	31	1.5	39*	0.5
O	1697	32	3.1	1750	33	1.2	−53**	1.9*
P	1780	35	2.7	1742	33	3.2	38*	−0.5
Overall	1732	31	2.2	1747	32	3.0	15	−0.8

Note. Planned comparisons: $^{**}p < .01$; $^{*}p < .05$.

oped in collaboration with the Technical Group of the Nijmegen Institute for Cognition and Information (NICI). The monitor was placed at a distance of approximately 60 cm from the participants in order to provide projection within the fovea of the eye. Stimuli appeared in lowercase Courier (18 points) at the center of the computer screen on a white background.

Participants received printed English instructions explaining that they had to identify English words that would gradually appear on the computer screen out of a background of visual noise. Participants were instructed to react as soon as they identified an English target word but without making errors.

At the beginning of each trial the words "NEXT WORD" were presented. After the participant pressed a button two small lines appeared, 6.6 mm (15 pixels) above and below the center of the screen. After 1500 ms, the screen was cleared and one of two checkerboard masks was presented at the center of the screen (covering the whole word matrix). One mask consisted of black and white blocks (checkerboard pattern) and the other was the inverse of it (black became white and white became black). The two masks were presented in turn. The mask presented on the first cycle of each trial was changed across participants. In the first cycle the mask appeared for 300 ms and was followed by the target word which was presented for 15 ms at the same position on the screen. Then the other mask was presented, but now for 285 ms, followed again by the target word for 30 ms, and so on. The time that the mask was visible decreased, while the time that the target word was visible increased until the mask presentation time was zero. The progressive demasking cycling process lasted until the participant pushed the response button or after 6 s when the participant did not respond. Immediately after the participants had pressed the button to indicate that they had identified the target word, this word was replaced by a checkerboard backward mask. At the same time, a dialog box appeared with the words "Enter the word." After the participants entered the word that they had identified, the next trial started.

The presentation order of the items was random and different for every participant. The experimental stimuli were presented in one block of 180 trials. Prior to the actual experiment, each participant completed a block of 32 practice trials containing the same types of English words as in the main experiment. The experimental session lasted about 30 min.

Results

The overall error rate was very low: 2.6%. Reaction times that fell outside two standard deviations of both the participant and item mean were considered to be outliers (1.3% of the data). Before running the analyses, both errors and outliers were removed. Table 2 presents the mean latencies, standard errors, and percentage errors in the different experimental conditions.

An analysis of variance was conducted including the within-participant factors of Condition (SOP, SO, SP, OP, O, and P) and Word Status (Test or Control). Since the selected items form a nonrandom and almost exhaustive selection of the item population, we ran analyses over participants only. The analysis showed a main effect of Condition [$F(5,195) = 5.49$, $p < .001$] and a nonsignificant effect of Word Status [$F(1,39) = 2.55$, $p = .11$]. Reaction times in the test conditions were somewhat faster (by 15 ms) than in the control conditions. More importantly, a significant interaction between Word Status and Condition was found [$F(5,195) = 7.32$, $p < .001$].

The RTs of test and control words within each condition were analysed in six planned comparisons. These planned comparisons indicated that the RTs for SOP, SO, and O test words were significantly faster than their matched controls [SOP: $F(1, 39) = 9.30$, $p < .01$; SO: $F(1, 39) = 5.50$, $p < .05$; O: $F(1,39) = 10.50$, $p < .01$]. The P and OP conditions, however, were found to be significantly slower than their matched control conditions [P: $F(1,39) = 5.50$, $p < .05$; OP: $F(1,39) = 4.95$, $p < .05$]. In the SP condition, RTs to control words and test words were not significantly different [SP: $F(1,39) = 1.87$, $p = .18$].

An analogous analysis of variance on the error rates in the different test and control conditions showed a main effect of Word Status [$F(1,39) = 6.22$, $p < .05$] and of Condition [$F(5,195) = 3.07$, $p < .05$]. Fewer errors were generally observed for test items than for control items. Furthermore, a significant interaction between Word Status and Condition was found [$F(5,195) = 3.48$, $p < .01$].

The errors of test and control words within each condition were analysed in six planned comparisons. These planned comparisons indicated that there were significantly fewer errors for SOP, SO (marginally), and SP test words than for their matched controls [SOP: $F(1,39) = 5.87$, $p < .05$; SO: $F(1,39) = 3.89$, $p = .06$; SP: $F(1,39) = 5.76$, $p < .05$]. In the OP and P conditions error rates to test words and control words were not significantly different [both $F(1,39) < 1$]. In the O condition test words led to more errors than their matched controls [$F(1,39) = 4.23$, $p < .05$].

Furthermore, we tested cognates (SO, SOP) and homographs (OP, O) as defined in most other studies against their matched controls. Cognates, having a mean RT of 1708 ms, were recognized significantly faster than their matched controls with a mean RT of 1751 ms [$F(1,39) = 12.51$, $p = .001$]. Homographs (1729 ms), however, were recognized about as fast as their controls (1737 ms) [$F(1,39) < 1$]. In the error analysis, fewer errors were made to cognates (1.5%) than to their controls (3.3%) [$F(1,39) = 11.11$, $p < .001$], but more errors were made to homographs (2.6%) than to their controls (1.4%) [$F(1,39) = 5.06$, $p < .05$].

Finally, we were interested to see if the inhibitory effect of phonological similarity reported above could also be detected at the level of individual items. Using the available subjective similarity scores for all test items (see section “Stimuli” above), we computed the Pearson correlation between the phonological similarity score for each item and its mean RT. The resulting positive correlation, $r = .26$, was significant at the 5% level. Thus, this analysis supports the earlier analyses with respect to the inhibitory contribution of phonological similarity to the RT. However, this correlation at item level should be interpreted with some caution, given that the amount of variability in the phonological similarity scores was relatively high between test conditions, but relatively low within conditions.

Discussion

Experiment 1 showed significant RT differences between particular types of cognates and interlingual homographs and their matched control words. The pattern of results is clearly not in accordance with a language selective access view because such a view would not predict any of these differences to arise. In this context we also note that the error rates for all test conditions and their matched control conditions either went in the same direction as the RTs or did not differ, the O condition being the only exception.

While the results support a language nonselective access view, they do not conform to a simple view that assumes faster RTs whenever the interlingual overlap in terms of the three codes (orthography, semantics, and phonology) increases. Rather, orthographic and semantic overlap leads to faster RTs, while phonological overlap induces slower RTs.[1]

These results help to explain why studies in the past have often observed facilitatory effects for cognates, but not for homographs. If the cognate materials in an experiment contain a mixture of SOP and SO stimuli, according to our study the overall result will still be facilitatory due to the combined facilitation produced by semantic and orthographic overlap. However, a mixture of OP and O interlingual homographs would be expected to induce much smaller facilitation effects relative to monolingual control items.

To obtain cross-experiment generality and to assess the "functional overlap" (Jacobs & Grainger, 1994) of different tasks, we decided to test our stimulus material in a different experimental paradigm. While the Dutch–English bilinguals in the first experiment performed the more recently developed progressive demasking task, the standard visual lexical decision task was used in Experiment 2. This makes Experiment 2 in some aspects comparable to the lexical decision study by Doctor and Klein (1992) who found inhibitory effects of phonological overlap in English–Afrikaans homographs. However, our lexical decision experiment differed from theirs in a number of respects. First, to be able to test exactly the same word stimuli as in Experiment 1, we performed an English lexical decision task without any other-language items rather than the generalized lexical decision task used by Doctor and Klein (1992). Furthermore, we systematically controlled cross-language phonological overlap for homograph stimuli and introduced the same systematic distinction for cognate items, where there is considerable semantic overlap between the two languages. Finally, in Doctor and Klein's study half of the nonwords were either English or Afrikaans pseudohomophones. Because it is well known from the monolingual word recognition literature that the introduction of pseudohomophones may affect the phonological processing of target words (e.g., Gibbs & Van Orden, 1998), we decided not to include this special type of nonword.

EXPERIMENT 2: LEXICAL DECISION WITH DUTCH–ENGLISH BILINGUALS

Method

Participants. Thirty Dutch students of the University of Nijmegen from the same population as in Experiment 1 took part in the experiment.

Stimuli. The 180 words and control words from the first experiment were used again. Since the lexical decision task also requires the inclusion of nonwords, an equal number of such stimuli were constructed. These were all orthographically regular and pronounceable strings of letters in English. They were derived from English words that were not in the set of experimental words by changing, adding, or deleting one or two letters.

Procedure. Presentation of the visual stimuli and recording of the RTs was controlled by an Apple Macintosh IIcx microcomputer. The same experimentation software and general stimulus presentation conditions were used as in Experiment 1.

Participants received printed English instructions. They were told that letter strings would appear on the screen one after another and that it was their task to decide as quickly and accurately as possible whether the strings were English words. In case of a word they had to press, with their right forefinger, the right-hand button of two buttons in front of them. In case of a nonword they had to press, with their left forefinger, the left-hand button. No left-handed participants participated in the experiment.

Each trial began with two slashes, one slightly above and one slightly below the mid-

[1] An inhibitory effect for low-frequency heterographic homophones relative to matched control items has also been reported in the monolingual domain by Davelaar et al. (1978, Experiment 3).

TABLE 3

Mean Response Times (RT, in Milliseconds), Standard Errors (SE), and Error Percentages (Error %) for All Test Conditions and Their Matched Controls in Experiment 2

	Test words			Control words				
Word type	RT	SE	Error %	RT	SE	Error %	RT effect	Error effect
SOP	593	13	10.6	618	11	15.5	−25**	−4.9*
SO	566	11	1.3	609	14	17.0	−43**	−15.7**
SP	615	13	15.8	625	17	15.4	−10	0.4
OP	608	17	16.7	600	11	8.0	8	8.7**
O	595	15	9.1	616	12	13.9	−21*	−4.8*
P	635	16	18.1	601	11	11.8	34**	6.3**
Overall	601	13	12.0	612	11	13.6	−11	−1.6

Note. Planned comparisons: $^{**}p < .01$; $^{*}p < .05$.

dle of the screen. The slashes served as a fixation point and stayed on the screen for 800 ms. There was an interstimulus interval of 300 ms prior to the letter string's appearance. Letter strings were presented in the middle of the screen and remained there until the participant responded or until a response limit, set at 1500 ms after stimulus onset, was reached. After the letter string's disappearance, there was an interval of 700 ms before the next trial started.

The presentation order of the test materials was random and different for every participant. The experimental stimuli were presented in three blocks of 120 trials. A pause of about 1 min occurred between two blocks. The next block began as soon as the participant was ready. Prior to the actual experiment, each participant completed a block of 32 practice trials containing the same types of stimuli as the experiment. The experimental session lasted approximately 45 min.

Results

The overall error rate was 9.2%, 12.6% for words and 5.9% for nonwords. Reaction times that fell outside 2 standard deviations of both the participant and item mean were considered to be outliers. In total 1.9% of the data were outliers. Both errors and outliers were removed before running the analysis. Table 3 shows the mean latencies, standard errors, and error percentages for the word target conditions. The mean RT to nonwords was 649 ms.

The same within-participant factors were used as in Experiment 1: Condition (SOP, SO, SP, OP, O, and P) and Word Status (Test or Control). An ANOVA run on the latencies of the word targets including these factors showed a main effect of Word Status [$F1(1,29) = 4.44$, $p < .05$] and Condition [$F(5,145) = 5.04$, $p < .001$]. Critically, the interaction between Word Status and Condition was also significant [$F1(5,145) = 9.11$, $p < .001$].

Planned comparisons were run for each of the six test conditions with their matched controls. As in Experiment 1, latencies for test words in the SOP, SO, and O conditions were significantly faster than in their matched control conditions [SOP: $F(1,29) = 7.73$, $p < .01$; SO: $F(1,29) = 23.57$, $p < .001$; and O: $F(1,29) = 4.75$, $p < .05$]. Test words in the P condition were significantly slower than their controls [$F(1,29) = 12.94$, $p = .001$]. The latencies for the test and control words did not differ significantly in the SP condition [$F(1,29) = 1.16$, $p = .29$] and in the OP condition [$F(1,29) < 1$].

An analogous analysis of variance on the error rates showed no main effect of Word Status [$F(1,29) = 2.49$, $p = .13$]. However, a main effect of Condition was observed [$F(5,145) = 5.01$, $p < .01$]. Furthermore, a significant interaction between Word Status and

Condition was found [$F(5,145) = 24.49$, $p < .001$]. The errors of test and control words within each condition were analyzed in six planned comparisons. There were significantly fewer errors for SOP, SO, and O test words than for their matched controls [SOP: $F(1,29) = 5.74$, $p < .05$; SO: $F(1,29) = 74.82$, $p < .001$; O: $F(1,29) = 4.59$, $p < .05$]. In the OP and P test conditions, however, there were more errors than in the matched control conditions [OP: $F(1,29) = 27.81$, $p < .001$; P: $F(1,29) = 10.13$, $p < .01$]. In the SP condition, error rates to test words and control words were not significantly different [$F(1,29) < 1$].

Furthermore, we tested cognates (SO, SOP) and homographs (OP, O) as defined in most other studies against their matched controls. Cognates had a mean RT of 579 ms and were recognized significantly faster than their matched controls with a mean RT of 614 ms [$F(1,29) = 31.34$, $p < .001$]. Homographs (601 ms), however, were recognized about as fast as their controls (608 ms) [$F(1,29) < 1$]. In the corresponding error analysis significant differences were found between cognates (6.0%) and their controls (16.3%) [$F(1,29) = 47.05$, $p < .001$], but not between homographs (13.0%) and their controls (10.9%) [$F(1,29) = 2.02$, $p = .17$].

Finally, we again computed the Pearson correlation between the phonological similarity score for each item and its mean RT. The resulting positive correlation again was $r = .26$, significant at 5% level. Once more, the analyses at stimulus category level and at item level show a slowing of RTs with increasing cross-language phonological similarity.

Discussion

Experiment 2 (lexical decision) replicated the pattern of results obtained in Experiment 1 (progressive demasking) to a large extent. Interlingual orthographic and semantic overlap facilitated lexical decision responses to target words, whereas phonological similarity with a nontarget language word resulted in significantly longer RTs. There was only one condition that produced different results in Experiments 1 and 2: the OP condition, which showed an inhibition effect in Experiment 1 but a null result in Experiment 2. Inspection of Table 2 shows that the mean RT in the OP control condition in Experiment 1 was fast not just with respect to its test condition, but also relative to the other control conditions, with which it was also rather well matched (as can be seen in Table 1). We therefore suggest that this OP effect was due to a theoretically uninteresting RT fluctuation in one control condition.

To further assess the similarity in response patterns on the two experiments, we computed a Pearson product-moment correlation coefficient between the two experiments using the 12 means for the latencies in test and control conditions. The observed value of .88 ($p < .001$) indicates that the RTs in the progressive demasking task in Experiment 1 can to a large degree be derived from the RTs in the visual lexical decision task of Experiment 2 by adding a constant (of about 1130 ms) reflecting differences in task characteristics. The strong similarity in the data of Experiments 1 and 2 provides additional evidence that there is a large “functional overlap” between the lexical decision and progressive demasking tasks (Jacobs & Grainger, 1994; see Schreuder & Baayen, 1997, and Carreiras, Perea, & Grainger, 1997, for further demonstrations).

In our English lexical decision task we found interlingual phonological inhibition effects just like Doctor and Klein (1992) did in their generalized English–Afrikaans lexical decision task. We think this is a more convincing demonstration of cross-language phonological influences in bilingual word recognition, since our participants only saw words of one language and did not receive any pseudohomophone stimuli. These aspects of our experimental design make it less likely that the observed phonological inhibition effect is merely strategic in nature.

Before we present a more elaborate account of our interpretation of these results, we note that all comparisons between test and control conditions in Experiments 1 and 2 are between-item comparisons. In order to make sure that the similar data patterns obtained in the two experiments were not due to specific characteristics

TABLE 4

Mean Response Times (RT, in Milliseconds), Standard Error (SE), and Error Percentages (Error %) for All Test Conditions and Their Matched Controls in Experiment 3

	Test words			Control words				
Word type	RT	SE	Error %	RT	SE	Error %	RT effect	Error effect
SOP	512	13	5.6	503	15	3.0	9	2.6
SO	490	14	2.9	499	13	5.9	−9	−3.0
SP	499	15	3.6	511	13	2.2	−12	1.4
OP	501	13	5.4	498	14	3.1	3	2.3
O	502	14	7.5	495	13	5.1	7	2.4
P	497	14	7.0	496	14	2.7	1	4.3*
Overall	501	13	5.4	500	13	3.7	1	1.7

Note. Planned comparisons: $**p < .01$; $*p < .05$.

of the items in the various test and control conditions, we decided to replicate Experiment 2 with monolingual English speaking participants. If the test and control items are indeed well matched, the RTs for monolingual participants in the different subconditions should not yield any significant differences.

EXPERIMENT 3: LEXICAL DECISION WITH AMERICAN ENGLISH MONOLINGUALS

Method

Participants. Thirty-one undergraduate and graduate students of the Pennsylvania State University participated in the experiment for course credit. All were native speakers of American English. After the experiment they filled in a questionnaire indicating their experience with foreign languages. Participants were considered to be “bilinguals” if (a) they had more than 5 years of experience with a second language, in particular German, French, or Spanish; or (b) they had learned more than two languages other than English (e.g., in high school). Eleven participants belonged to this category. The remaining 20 participants were considered to be “American English monolinguals” and only their data were analyzed.

Stimuli. The 180 words and control words from Experiment 2 were used in this experiment. Almost all of the 180 nonwords from Experiment 2 were also included, with the exception of 10 nonwords that turned out to be either very low-frequency words in American English (e.g., MULCH, SHALE) or taboo words. These items were replaced by similarly constructed different nonwords.

Procedure. Presentation of the visual stimuli and recording of the RTs was controlled by an Apple Macintosh IIsi microcomputer. The same experimentation software, stimulus presentation conditions, and English instructions were used as in Experiment 2. There was no mention to the participants of the fact that some of the English test words were also Dutch words or sounded like them.

Results

The overall error rate was 7.4%, 5.4% for words and 9.4% for nonwords. Three items were found to have an error rate above 50% (FAY, POX, and WALE). It was decided to exclude these items and their matched counterparts (FAY, POX, WALE, and JURY) from further analysis.[2] Reaction times that fell outside 2 standard deviations of both the participant and item mean were considered to be outliers. In total 1.5% of the remaining data were

[2] Reanalysis of the data from Experiment 2 leaving out these four items did not result in any change in the statistically significant result pattern for the bilingual participants.

outliers. Both errors and outliers were removed before running the analyses. Table 4 shows the mean latencies and error scores for the word target conditions. The mean RT to nonwords was 575 ms.

The same within-participant factors were used as in Experiments 1 and 2: Condition (SOP, SO, SP, OP, O, and P) and Word Status (Test or Control). An ANOVA run on the latencies of the word targets including these factors showed neither a main effect of Word Status [$F(1,19) < 1$] nor of Condition [$F(5,95) = 1.32$, $p = .26$]. The interaction between Word Status and Condition was not significant either [$F(5,95) = 1.34$, $p = .25$]. Planned comparisons were run for each of the six test conditions with their matched controls. In contrast to Experiments 1 and 2, none of these comparisons led to significant effects [SOP: $F(1,19) = 1.59$, $p = .22$; SO: $F(1,19) = 1.72$, $p = .21$; SP: $F(1,19) = 2.04$, $p = .17$; OP, O, and P: all $F(1,19) < 1$].

An analysis of variance on the error rates in the different test and control conditions showed a main effect of Word Status [$F(1,19) = 7.83$, $p < .05$] but only a trend toward an effect of Condition [$F(5,95) = 2.06$, $p = .08$]. The interaction between Word Status and Condition was not significant either [$F(5,95) = 1.97$, $p = .09$]. To find out more about the origin of the trend toward interaction, the errors of test and control words within each condition were analyzed in six planned comparisons. These planned comparisons indicated that there were significantly more errors in the P test condition than in its matched control condition [$F(1,19) = 4.97$, $p < .05$]. However, in the other conditions, error rates to test words and control words were not significantly different [SOP: $F(1,19) = 2.70$, $p = .12$; SO: $F(1,19) = 2.46$, $p = .13$; SP: $F(1,19) < 1$; OP: $F(1,19) = 2.09$, $p = .17$; and O: $F(1,19) = 1.84$, $p = .19$].

Discussion

In Experiment 3, American English monolinguals performed the same lexical decision task involving the same stimulus material as the Dutch–English bilinguals did in Experiment 2. In general, the RTs of the monolinguals were 106 ms faster than those of the bilingual participants in Experiment 2, which is not unexpected given the present participants' higher proficiency in English. Furthermore, the RTs in the 12 test and control conditions all lie very close together within a range of 12 ms around an average of 500 ms. Despite a combination of fast RTs and small standard errors, significant RT differences were observed neither between test and control conditions, nor between the test conditions alone. With only one exception, the test and control conditions did not differ with respect to error rates either. The exception can possibly be explained by some imperfectly matched item characteristic for this specific group of American English bilinguals (e.g., neighborhood density).

To conclude, the data from the monolingual participants in Experiment 3 indicate that the very similar result patterns across Experiments 1 and 2 must be ascribed to the bilinguals' processing of the items in the various test and control conditions.

GENERAL DISCUSSION

In two different experimental paradigms, progressive demasking and lexical decision, Dutch–English bilinguals produced a stable and almost identical pattern of RTs to interlingual homographs, homophones, and cognates that differed from matched control words in terms of their orthographic, semantic, and phonological overlap with words from the nontarget language. While orthographic and semantic overlap were shown to result in facilitatory effects relative to controls, phonological overlap induced inhibition. A control experiment, involving lexical decision by American English monolinguals, showed that this pattern of results cannot be ascribed to differences in the characteristics of the test and control items used. The obtained bilingual results have a number of important theoretical implications, which we discuss in turn.

Language-Selective Versus Nonselective Access

The bilingual data patterns clearly reject a language-selective access hypothesis and in-

TABLE 5

Mean Response Times in Milliseconds for Cognates (SOP, SO), Homographs (O, OP), and Their Matched Controls in English Lexical Decision (Experiment 2 of This Study) and the LFE–LFD Condition of Experiment 1 by Dijkstra, Van Jaarsveld, & Ten Brinke (1998)

	Cognate	Control	Effect	Homograph	Control	Effect
Experiment 2	579	614	−35	601	608	−7
Dijkstra et al. (1998)	593	630	−37	620	627	−7

stead favor a language-nonselective access hypothesis with respect to both form (orthographic and phonological) and meaning (semantic) dimensions. The data indicate that the bilingual processing system is highly interactive because all three types of codes were found to affect the RTs. In an exclusively English task context, Dutch–English bilinguals were affected in their reactions by the similarity of the English targets to Dutch words on all three dimensions.

By distinguishing the orthographic and phonological components of cognates and homographs, this study clarifies those by Dijkstra et al. (1998) and by De Groot, Delmaar, and Lupker (in press). In fact, a direct comparison of this experiment to Experiment 1 by Dijkstra et al. (1998) is possible because both experiments were conducted using bilingual participants from the same population with almost identical computer hardware and experimentation software. Dijkstra et al. (1998) also had Dutch–English bilinguals perform an English lexical decision task involving interlingual homographs, cognates, and English control words. However, while our study involved a manipulation of the cross-linguistic similarity of the different codes that characterize word items (orthography, phonology, and semantics), Dijkstra et al. (1998) manipulated the relative frequency of the readings of interlingual homographs and cognates in English and Dutch. In their experiment, the RTs to Dutch–English homographs were not clearly affected by the word frequency of their Dutch counterparts, in contrast to the cognate items that did show significant facilitation effects compared to exclusively English control words.

Table 5 shows the striking similarity in mean RTs for comparable groups of cognates and homographs in the two studies. The statistical pattern of results is also the same across the two studies. In combination, the results indicate that both the relative frequency and the cross-linguistic form and meaning similarity of the items affect RTs. Future research should investigate in which way these two important characteristics of bilingual items interact during the language nonselective lexical access process.

Resolving Conflicting Evidence in the Empirical Literature

In their Experiment 1, Dijkstra et al. (1998) obtained null results for interlingual homographs relative to matched control items. The current study clarifies these null effects by distinguishing the contribution of orthographic and phonological information to the lexical decision response. Experiment 2 of our study clearly demonstrates that when phonological overlap is minimized (as in the O condition), facilitatory effects of interlingual homography do arise. However, failing to control for phonological similarity in the homograph stimuli tested will, according to the present results, generate an overall effect on the RT that combines the positive influence of orthographic overlap and the negative influence of phonological overlap (e.g., OP condition). This reasoning also helps to explain why many other previous studies testing interlingual homographs failed to find significant RT differences relative to nonhomographic controls (e.g., De Bot et al., 1995; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998, Experiment 1; Gerard & Scarborough, 1989). In sum, a significant contribution of the present study is the demonstration of a negative influence of cross-linguistic phonological similarity on word recognition latencies in bilinguals.

We obtained further support for this theoretical position by computing the mean degree of phonological overlap presented in the complete set of cognates and homographs in Experiment 1 by Dijkstra et al. (1998). The obtained mean phonological similarity score for cognates was 5.0, while in our SOP and SO conditions it was 4.5. For interlingual homographs, it was 5.1, compared to 4.3 in our OP and O conditions. In other words, many of the cognates used by Dijkstra et al. (1998) should be considered, in our terms, strong SOP items while many of their homographs were strong OP items (see Table 1). Thus, the null effects for interlingual homographs observed by Dijkstra et al. may reflect the elimination of facilitatory effects due to cross-linguistic orthographic identity by inhibitory effects due to cross-linguistic phonological similarity.[3]

Distinct Contributions of Different Codes to Bilingual Word Recognition

The finding that all three information sources (orthographic, semantic, and phonological) contribute to the overall response implies that their effects should theoretically and methodologically be distinguished. This can be nicely illustrated by fitting the following linear regression model to the data for each of the two bilingual experiments in this study. Let us assume that the reaction times in both experiments are determined by a linear combination of a task-specific component (tc) and a contribution of semantic (S), orthographic (O), and phonological (P) sources: RT = tc + S + O + P. The weight of the S, O, and P factors for a particular item category is set at 1 if overlap is present and at 0 if it is absent. Using the six means in the different test conditions and the overall mean of the control conditions, we obtain two linear regression equations with corresponding R^2 correlations. Experiment 1 (progressive demasking) resulted in the equation RT = 1743 (tc) − 28 (S) − 27 (O) + 34 (P) and an R^2 of .86; Experiment 2 (bilingual lexical decision) in RT = 613 (tc) − 21 (S) − 23 (O) + 21 (P) and an R^2 of .98. In contrast, Experiment 3 (monolingual lexical decision) resulted in the equation RT = 495 (tc) − 1 (S) + 4 (O) + 6 (P) with an accompanying R^2 of only .25.[4] The striking similarity of the two independent regression equations across the two bilingual experiments (with different groups of participants) testifies to the large functional overlap that must exist between the two paradigms. In other words, the contributions of orthographic, semantic, and phonological information sources to the RTs are relatively task independent and are, at least in these experiments, remarkably similar in absolute size.

Extending the Bilingual Interactive Activation Model of Bilingual Word Recognition

We now consider how the apparently opposite effects of phonology on the one hand, and orthography and semantics on the other, can be interpreted in terms of structural characteristics of the bilingual processing system and/or participant strategies.

Although the English and Dutch word forms of the homographic test words are always completely identical in terms of their orthography, there is almost never a 100% phonological overlap for the homophonic items due to the differences in phoneme repertoire of these languages. According to a straightforward structural interpretation then, orthographically identical cognates and interlingual homographs can be identified faster than matched controls because they share lexical and sublexical orthographic representations across languages. This sharing leads to stronger activation of the orthographic repre-

[3] Note that, if this account applies, one need not assume (as Dijkstra et al. did) that in their experiment the nontarget language was less activated than the target language due to the composition of the stimulus list.

[4] The weight of the S, O, and P factors can also be represented by the means of the obtained subjective similarity score for each word type (see Stimuli section in Experiment 1). Using the six mean similarity scores for the different test conditions and the overall mean similarity score of the control conditions, Experiment 1 resulted in the equation RT = 1746 (tc) − 5.3 (S) − 7.2 (O) + 10.1 (P) and an R^2 of .86. For Experiment 2, we obtained the equation RT = 616 (tc) − 4.2 (S) − 5.4 (O) + 6.7 (P) and an R^2 of .97. The corresponding equation for Experiment 3 was RT = 495 (tc) − .36 (S) + .39 (O) + 1.04 (P) with an R^2 of .14.

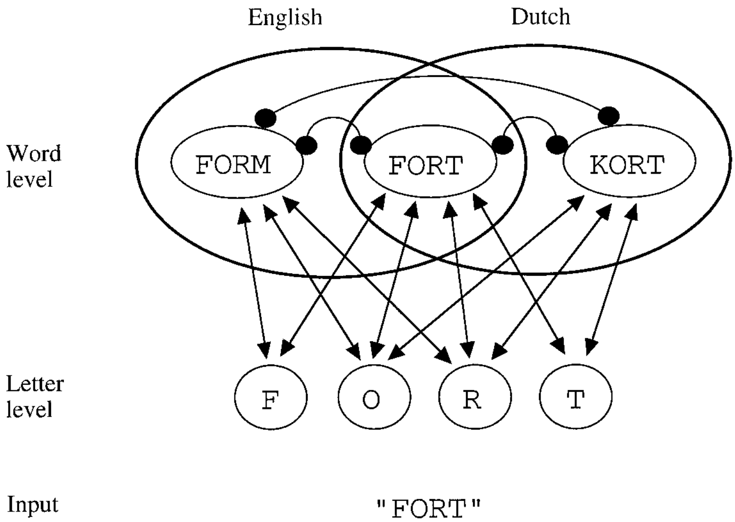

FIG. 1. A possible representation of interlingual homographs in the BIA model. A shared orthographic representation is assumed for form-identical items belonging to different languages. Lexical representations have bidirectional connections to their constituent letter representations and are also directly connected to the corresponding semantic and phonological representations (not shown).

sentations during recognition and therefore to faster RTs.

In contrast, the phonological inhibition effect arises because two distinct phonological representations are activated in the two languages. Since several phoneme representations differ between English and Dutch, the lexical representations made up by these phonemes are also different. Phonological inhibition now occurs because, after a given letter string activates all compatible phonological codes independent of language (Brysbaert et al., 1999; Nas, 1983), the activated nonidentical phonological lexical representations may compete at a lexical level (e.g., through lateral inhibition). This competition results in a delayed identification of the item in the target language.

Finally, following De Groot (1992), it may be assumed that the meaning of words is represented in terms of distributed semantic features. The cross-linguistic semantic similarity present in cognate items will then lead to facilitation relative to controls because both readings of a cognate to a large extent activate the same semantic features.

This theoretical interpretation of the present results can easily be integrated into an extended version of the Bilingual Interactive Activation (BIA) model of bilingual visual word recognition that incorporates phonology and semantics (Dijkstra & Van Heuven, 1998; Grainger & Dijkstra, 1992; Van Heuven, Dijkstra, & Grainger, 1998). This extended model assumes that interlingual homographs have a common whole-word orthographic representation, shown in Fig. 1, that activates in parallel all corresponding semantic and phonological codes. These two latter types of representations are also connected.

The assumption of one orthographic lexical representation for ambiguous word forms is also made by interactive activation models for word recognition in the monolingual domain (e.g., Gernsbacher & St. John, in press). Both empirically and theoretically the presented model would therefore seem to account for all findings in the present study in a plausible and elegant way.

However, other data available in the experimental literature are not so easily accounted for within this view. First, in two lexical decision experiments Dijkstra et al. (1998, Experiments 2 and 3) found that the size of the RT differences between interlingual homographs and controls depended on the relative word frequencies of the items in the target and other language. It is hard to see how the two word frequencies of the readings of an interlingual homograph could differentially affect recognition time if both belong to only one lexical representation, as with the model presented in Fig. 1. Assuming a shared cross-linguistic representation, one might expect that summed word frequency across languages rather than relative frequency would be the most important determinant of the RTs. However, the assumption of a shared lexical representation across languages can be salvaged by considering word frequency not as a characteristic of the lexical representations themselves but of the connections between representations (e.g., letters and words or words and concepts).

Second, if it is the competition between different phonological representations that underlies the present inhibitory effects for incomplete P-overlap, imperfect O-overlap should logically also induce inhibition effects. However, there is evidence that facilitation effects can arise for cognates that are only similar and not identical in their orthographic form, at least in tasks involving word pairs (e.g., De Groot & Nas, 1991; De Groot & Poot, 1997; Dufour & Kroll, 1995; Sanchez-Casas, Davis, & Garcia-Albea, 1992; Van Hell & De Groot, 1998). It is therefore conceivable that just orthographic similarity or partial overlap in letters (perhaps only in combination with semantic similarity) is enough to induce facilitation effects. For instance, in a dynamic system both similarity and identity in orthographic form (and/or meaning) might allow a faster "zooming in" on the correct target word than in case of a control word.

Third, Dijkstra et al. (1998, Experiment 2) and Dijkstra, Timmermans, and Schriefers (submitted) showed that under some circumstances orthographically identical interlingual homographs may be inhibited rather than facilitated (e.g., when words from a nontarget language are included in the experiment that have to be treated as nonwords or must be ignored). Under the assumption of shared orthographic representations for interlingual homographs, such inhibition effects can only originate from external sources (for instance, all items belonging to a particular language, including the homographs, might be inhibited by a language node). In other words, the observed orthographic inhibition effects could be strategic and/or task dependent. But if this is true, the inhibitory P-effects in our experiments could also be strategic in nature. For instance, they could reflect the participants' attempt to suppress phonological activation arising in their integrated lexicon because in the context of the experiment as a whole, phonology is perhaps not a reliable information source and should be avoided. This suppression would then show up as inhibition in the test conditions where phonological overlap is present (SOP, OP, SP, and P).

In sum, we must keep in mind that observed facilitation and inhibition effects are not necessarily a direct reflection of underlying characteristics of the bilingual processing system, but may indicate how this system is used under specific experimental circumstances (Dijkstra et al., 1998; Green, 1998). These considerations suggest that we should not dismiss an extension of the BIA model that assumes two orthographic representations, one for each language. The orthographic component of this alternative variant is depicted in Fig. 2.

In Fig. 2, form-identical cognates and interlingual homographs have their own whole-word orthographic representation for each language. In other words, they are represented in the same way as items that are similar but not identical in form across languages, such as WORK–WERK (nonidentical cognates) or WORK–WORP (word neighbors). In addition, each representation is characterized by its word frequency in the language it belongs to. With respect to semantics and phonology, the model in Fig. 2 provides similar accounts to the model presented in Fig. 1. However, with respect to orthography, the interpretation of the facilitation effect is rather different.

The model in Fig. 2 proposes an integration of codes at sublexical levels (e.g., in terms of the letters), but not at the lexical level. Here orthographic units are distinct for different languages in order to stress the different functionality of such codes. For instance, the orthographic representa-

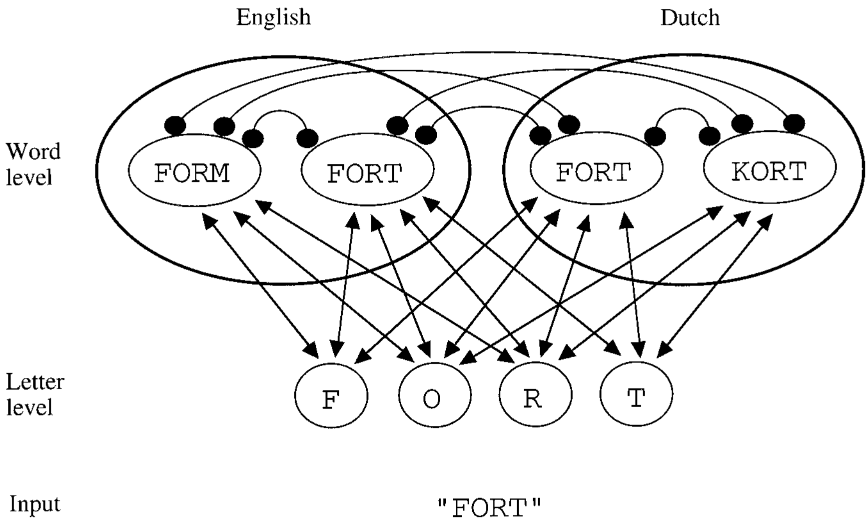

FIG. 2. An alternative representation of interlingual homographs in the BIA model. Two orthographic representations are assumed for form-identical items belonging to different languages. Both lexical representations are bidirectionally connected to their constituent letter representations, allowing mediated facilitation effects. Connections to the corresponding semantic and phonological representations are not shown but are identical to those assumed for the model in Fig. 1.

tion of a word in a language is characterized by the frequency of the word in that particular language. The model in Fig. 2 can still explain the orthographic facilitation effect as the result of mediated facilitation at sublexical levels (via their shared letters the two orthographic representations of an interlingual homograph strengthen each other) or as a consequence of stronger evidence that a lexical representation is available in case of a homograph relative to a control (two representations rather than one).

Thus, while the model presented in Fig. 1 can account in a simple way for the the interaction of different codes observed in the present experiments, the model in Fig. 2 can most easily account for the frequency data by Dijkstra, Van Jaarsveld, and Ten Brinke (1998), De Groot, Delmaar, and Lupker (in press), and Dijkstra, Timmermans, and Schriefers (submitted).[5] Comparing these and other models by means of simulation studies or testing them in empirical studies will be important aims for future research.

It is too early to tell which model will finally survive these tests, but the present data set important constraints on its architecture: The model will need to be nonselective in nature, and it will make clear distinctions between the sometimes opposite contributions of phonological, orthographic, and semantic codes to the bilingual word recognition process.

[5] The simulations of this last study in Dijkstra and Van Heuven (1998) demonstrate this point.

APPENDIX

Stimulus Material

For each word type, the English target items are presented with their IPA representation, their major Dutch competitors with their IPA representations, and the targets' paired English control items.

Word Type: SOP Cognates

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
hotel	həʊtɛl	hotel	hoːtɛl	event
film	fɪlm	film	fɪlm	bird
lip	lɪp	lip	lɪp	sky
tent	tɛnt	tent	tɛnt	luck
sport	spɔːt	sport	spɔrt	guilt

Word Type: SOP Cognates (*cont.*)

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
trend	trɛnd	trend	trɛnt	pride
storm	stɔːm	storm	stɔrm	thigh
fort	fɔːt	fort	fɔrt	silk
pen	pɛn	pen	pɛn	fur
sofa	səʊfə	sofa	soːfaː	wage
net	nɛt	net	nɛt	lad
mist	mɪst	mist	mɪst	bold
rib	rɪb	rib	rɪp	cab
torso	tɔːsəʊ	torso	tɔrzoː	trash
ark	ɑːk	ark	ɑrk	flu

Word Type: SO Cognates

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
type	taɪp	type	tiːpə	nice
wild	wɜld	wild	wɪlt	desk
model	mɒdl̩	model̩	moːdɛl	skill
fruit	fruːt	fruit	frœyt	youth
pure	pjʊə̊	pure	pyːrə	soil
jury	dʒʊərI	jury	ʒyːriː	wale
code	kəʊd	code	koːdə	tale
mild	maɪld	mild	mɪlt	chin
humor	hjuːmə̊	humor	hyːmɔr	fever
rat	ræt	rat	rɑt	jaw
oven	ʌvn̩	oven	oːvə	chap
chaos	keɪɒs	chaos	xaːɔs	spine
ego	ɛgəʊ	ego	eːɣoː	pea
globe	gləʊb	globe	xloːbə	torch
menu	mɛnjuː	menu	meːnyː	bike

Word Type: SP Cognates

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
news	njuːz	nieuws	niːws	lady
fat	fæt	vet	vɛt	tea
boat	bəʊt	boot	boːt	tall
cool	kuːl	koel	kuːl	iron
tone	təʊn	toon	toːn	suit
wheel	wiːl	wiel	wiːl	chain

Word Type: SP Cognates (*cont.*)

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
clock	klɒk	klok	klɔk	giant
cliff	klɪf	klif	klɪf	straw
ankle	æŋkl̩	enkel	ɛnkəl	unity
soup	suːp	soep	suːp	ropt
sock	sɒk	sok	sɔk	dusk
rack	ræk	rek	rɛk	brow
cord	kɔːd	koord	koːrt	scar
nymph	nɪmf	nimf	nɪmf	batch
fay	feɪ	fee	feː	pox

Word Type: OP False Friends

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
step	stɛp	step	stɛp	skin
star	stɑː̊	star	stɑr	king
box	bɒks	box	bɔks	gun
spot	spɒt	spot	spɔt	wing
pink	pɪŋk	pink	pɪŋk	song
brief	briːf	brief	briːf	funny
arts	ɑːts	arts	ɑrts	twin
bond	bɒnd	bond	bɔnt	lawn
pet	pɛt	pet	pɛt	pie
pit	pɪt	pit	pɪt	fox
stout	staʊt	stout	stɑʊt	eagle
dot	dɒt	dot	dɔt	cue
rover	rəʊvə̊	rover	roːvər	peach
brink	brɪŋk	brink	brɪŋk	crook
kin	kɪn	kin	kɪn	ale

Word Type: O False Friends

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
stage	steɪdʒ	stage	staːʒə	mouth
glad	glæd	glad	xlɑt	coat
roof	ruːf	roof	roːf	sale
boon	buːn	boon	boːn	hero
steel	stiːl	steel	steːl	rough
boot	buːt	boot	boːt	acre
lover	lʌvə̊	lover	loːvər	entry

Word Type: O False Friends (*cont.*)

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
fee	fiː	fee	feː	mud
tube	tjuːb	tube	tyːbə	lion
angel	eɪnʒəl	angel	ɑŋəl	elbow
lap	læp	lap	lɑp	jar
brave	breɪv	brave	braːvə	crude
rug	rʌg	rug	rʉx	shy
brand	brænd	brand	brɑnt	gown
sage	seɪdʒ	sage	saːɣə	flea

Word Type: P False Friends

English test word		Dutch competitor word		English control word
Spelling	Phonology	Spelling	Phonology	Spelling
note	nəut	noot	noːt	army
leaf	liːf	lief	liːf	fair
lack	læk	lek	lɛk	duty
aid	eɪd	eed	eːt	odd
lake	leɪk	leek	leːk	holy
lane	leɪn	leen	leːn	wire
cow	kau	kou	kɑu	gap
pace	peɪs	pees	peːs	fate
mail	meɪl	meel	meːl	pity
core	kɔː̊	koor	koːr	cage
ray	reɪ	ree	reː	bee
scent	sɛɑnt	cent	sɛnt	mercy
dose	dəus	doos	doːs	fame
stale	steɪl	steel	steːl	alley
oar	ɔː̊	oor	oːr	oat

REFERENCES

Baayen, H., Piepenbrock, R., & Van Rijn, H. (1993). *The CELEX lexical database (CD-ROM).* Philadelphia, PA: Univ. of Pennsylvania Linguistic Data Consortium.

Beauvillain, C., & Grainger, J. (1987). Accessing interlexical homographs: Some limitations of a language selective access. *Journal of Memory and Language,* **26,** 658–672.

Brysbaert, M., Van Dyck, G., & Van de Poel, M. (1999). Visual word recognition in bilinguals: Evidence from masked phonological priming. *Journal of Experimental Psychology: Human Perception and Performance* **25,** 137–148.

Caramazza, A., & Brones, I. (1979). Lexical access in bilinguals. *Bulletin of the Psychonomic Society,* **13,** 212–214.

Carreiras, M., Perea, M., & Grainger, J. (1997). Effects of orthographic neighborhood in visual word recognition: Cross-task comparisons. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **23,** 857–871.

Cristoffanini, P., Kirsner, K., & Milech, D. (1986). Bilingual lexical representation: The status of Spanish-English cognates. *Quarterly Journal of Experimental Psychology,* **38A,** 367–393.

Davelaar, E., Coltheart, M., Besner, D., & Jonasson, J. T. (1978). Phonological recoding and lexical access. *Memory & Cognition,* **6,** 391–402.

De Bot, K., Cox, A., Ralston, S., Schaufeli, A., & Weltens, B. (1995). Lexical processing in bilinguals. *Second Language Research,* **11,** 1–19.

De Groot, A. M. B. (1992). Bilingual lexical representation: A closer look at conceptual representations. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 389–412). Amsterdam: Elsevier.

De Groot, A. M. B., Delmaar, P., & Lupker, S. J. (in press). The processing of interlexical homographs in a bilingual and a monolingual task: Support for nonselective access to bilingual memory. *Quarterly Journal of Experimental Psychology.*

De Groot, A. M. B., & Nas, G. L. J. (1991). Lexical representation of cognates and noncognates in compound bilinguals. *Journal of Memory and Language,* **30,** 90–123.

De Groot, A. M. B., & Poot, R. (1997). Word translation at three levels of proficiency in a second language: The ubiquitous involvement of conceptual memory. *Language Learning,* **47,** 215–264.

Dijkstra, A., & Van Heuven, W. J. B. (1998). The BIA-model and bilingual word recognition. In J. Grainger & A. Jacobs (Eds.), *Localist connectionist approaches to human cognition* (pp. 189–225). Hillsdale NJ: Erlbaum.

Dijkstra, A., Timmermans, M., & Schriefers, H. (submitted). On being blinded by your other language: Effects of task demands on interlingual homograph recognition.

Dijkstra, A., Van Jaarsveld, H., & Ten Brinke, S. (1998). Interlingual homograph recognition: Effects of task demands and language intermixing. *Bilingualism,* **1,** 51–66.

Doctor, E. A., & Klein, D. (1992). Phonological processing in bilingual word recognition. In R. J. Harris (Ed.), *Cognitive processing in bilinguals* (pp. 237–252). Amsterdam: Elsevier.

Dufour, R., & Kroll, J. F. (1995). Matching words to concepts in two languages: A test of the concept mediation model of bilingual representation. *Memory and Cognition,* **23,** 166–180.

Durgunoglu, A. Y., & Roediger III, H. L. (1987). Test differences in accessing bilingual memory. *Journal of Memory and Language,* **26,** 377–391.

Ferrand, L., & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *Quarterly Journal of Experimental Psychology,* **47A,** 365–382.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin,* **123,** 71–99.

Gerard, L. D., & Scarborough, D. L. (1989). Language-specific lexical access of homographs by bilinguals. *Journal of Experimental Psychology: Learning, Memory and Cognition,* **15,** 305–313.

Gernsbacher, M. A., & St. John, M. F. (in press). Modeling the mechanism of suppression in lexical access. In R. Klein & P. McMullen (Eds.), *Converging methods for studying reading and dyslexia.* Cambridge, MA: MIT Press.

Gibbs, P., & Van Orden, G. (1998). Pathway selection's utility for control of word recognition. *Journal of Experimental Psychology: Human Perception and Performance,* **24,** 1162–1187.

Gollan, T. H., Forster, K. I., & Frost, R. (1997). Translation priming with different scripts: Masked priming with cognates and noncognates in Hebrew–English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **23,** 1122–1139.

Grainger, J. (1993). Visual word recognition in bilinguals. In R. Schreuder & B. Weltens (Eds.), *The bilingual lexicon* (pp. 11–26). Amsterdam/Philadelphia: Benjamins.

Grainger, J., & Beauvillain, C. (1987). Language blocking and lexical access in bilinguals. *Quarterly Journal of Experimental Psychology,* **39A,** 295–319.

Grainger, J., & Dijkstra, A. (1992). On the representation and use of language information in bilinguals. In R. J. Harris (Ed.), *Cognitive processing in bilinguals* (pp. 207–220). Amsterdam: Elsevier.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review,* **103,** 518–565.

Grainger, J., & Segui, J. (1990). Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies. *Perception and Psychophysics,* **47,** 191–198.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism,* **1,** 67–81.

Grosjean, F. (1997). Processing mixed language: Issues, findings, and models. In A. M. B. De Groot & J. F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives* (pp. 225–254). Hillsdale, NJ: Erlbaum.

Jacobs, A. M., & Grainger, J. (1994). Models of visual word recognition: Sampling the state of the art. *Journal of Experimental Psychology: Human Perception and Performance,* **20,** 1311–1334.

Keatley, C. W. (1992). History of bilingualism research in cognitive psychology. In R. J. Harris (Ed.), *Cognitive processing in bilinguals* (pp. 15–49). Amsterdam: Elsevier.

Lam, A. S. L., Perfetti, C. A., & Bell, L. (1991). Automatic phonetic transfer in bidialectal reading. *Applied Psycholinguistics,* **12,** 299–311.

Macnamara, J., & Kushnir, S. (1971). Linguistic independence of bilinguals: The Input Switch. *Journal of Verbal Learning and Verbal Behavior,* **10,** 480–487.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception. Part 1. An account of basic findings. *Psychological Review,* **88,** 375–405.

McClelland, J. L., & Rumelhart, D. E. (1988). *Parallel distributed processing: Explorations in the microstructure of cognition* (Vol. 3). Cambridge: Bradford Books.

Nas, G. (1983). Visual word recognition in bilinguals: Evidence for a cooperation between visual and sound based codes during access to a common lexical store. *Journal of Verbal Learning and Verbal Behavior,* **22,** 526–534.

Perfetti, C. A., & Bell, L. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and priming. *Journal of Memory and Language,* **30,** 473–485.

Sánchez-Casas, R., Davis, C. W., & García-Albea, J. E. (1992). Bilingual lexical processing: Exploring the cognate/non-cognate distinction. *European Journal of Cognitive Psychology,* **4,** 311–322.

Scarborough, D. L., Gerard, L., & Cortese, C. (1984). Independence of lexical access in bilingual word recognition. *Journal of Verbal Learning and Verbal Behavior,* **23,** 84–99.

Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. *Journal of Memory and Language,* **37,** 118–139.

Sears, C. R., Hino, Y., & Lupker, S. (1995). Neighborhood size and neighbor frequency effects in word recognition. *Journal of Experimental Psychology: Human Perception and Performance,* **21,** 876–900.

Snodgrass, J. G., & Mintzer, M. (1993). Neighborhood effects in visual word recognition: Facilitatory or inhibitory? *Memory and Cognition,* **21,** 247–266.

Soares, C., & Grosjean, F. (1984). Bilinguals in a monolingual and bilingual speech mode: The effect on lexical access. *Memory and Cognition,* **12,** 380–386.

Tzelgov, J., Henik, A., & Leiser, D. (1990). Controlling Stroop interference: Evidence from a bilingual task. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **16,** 760–771.

Tzelgov, J., Henik, A., Sneg, R., & Baruch, O. (1996). Unintentional word reading via the phonological route: The Stroop effect with cross-script homophones. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **22,** 336–349.

Van Hell, J. G., & De Groot, A. M. B. (1998). Conceptual representation in bilingual memory: Effects of concreteness and cognate status in word association. *Bilingualism,* **1,** 193–211.

Van Heuven, W. J. B., Dijkstra, A., & Grainger, J. (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language,* **39,** 458–483.

Van Orden, G. C. (1987). A ROWS is a ROSE: Spelling, sound, and reading. *Memory & Cognition,* **15,** 181–198.

Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **14,** 371–386.

Winer, B. J. (1971). *Statistical principles in experimental design.* London: McGraw–Hill.

Ziegler, J., & Jacobs, A. (1995). Phonological information provides early sources of constraint in the processing of letter strings. *Journal of Memory and Language,* **34,** 567–593.

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