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Abstract

This study examined the role of phonological and orthographic overlap in the recognition of cognate words by recording electrophysiological and behavioral data. One hundred and ninety-two words were selected: 96 cognate words listed according to their phonological and orthographic overlap vs. 96 noncognate words. Twenty-four proficient European Portuguese-English bilinguals performed a silent reading task with a masked priming paradigm. The results showed that phonology interacts with semantic activation at N400 modulations. Phonological priming effects were dependent on the orthographic overlap of cognate words. Thus, the distinctive processing of cognate words seems to be due to their cross-linguistic similarity, which is consistent with a localist connectionist account on cognate representation and processing.

Keywords: cognate words; phonological and orthographic overlap; masked priming

Introduction

A vast amount of research in cognitive psychology has used masked priming techniques to explore the role played by phonological information in tasks where no articulatory output is required (silent reading or lexical decision), both in monolinguals (1,2) and bilinguals (2,3). According strong phonological accounts (4) phonology operates quickly and automatically and its effect in priming paradigms should be greater the lower graphemic similarity is between prime and target. Most studies that explored how fast phonological information is activated during word processing have used target words preceded by masked pseudohomophone and homophone prime words, whereas just one has used cognate words as primes (5). Cognates are equivalent translations that share both form and meaning (e.g., *papel* in European Portuguese (EP) and paper in English).

For researchers investigating bilingual word recognition, phonological, orthographic and semantic similarities across languages are interesting because they may reveal how the bilingual lexicon is accessed and organized (2). Previous priming and nonpriming studies using cognates have pointed to an integrated lexicon with nonselective access for the two languages (2, 3, 6, 7). However, how phonology interacts with orthography at the initial stages of cognate word recognition remains controversial (2, 6, 7). Thus, the general aim of the present study is to examine the interplay of phonology and orthography in cognate word processing by combining for the first time masked priming and Event-Related potentials (ERPs) techniques.

Using the masked priming procedure, Voga and Grainger (5) showed phonological priming effects in cognate word processing when there is a null orthographic overlap. In that study, a group of Greek-French bilinguals had to decide whether the sequence of letters presented in French (second language-L2) and preceded by masked Greek (first language –L1) cognate and noncognate words was a word or not (lexical decision task –LDT). Cognates had a high vs. low phonological overlap. The findings indicated a facilitatory priming effect for cognates and noncognates relative to unrelated controls and, more importantly, this effect increased as a function of the amount of phonological overlap. The cognate advantage was interpreted as resulting from additional phonological priming. However, as Greek-French cognates have a null orthographic similarity, we do not know whether these results can be extended to languages with the same alphabet.

There are a few nonpriming studies that have also examined the influence of phonological and orthographic overlap of cognates in both comprehension (6) and production tasks (7) in languages that share the same alphabet. One of those studies analyzed how cross-linguistic similarity affects Dutch-English identical and non-identical cognate recognition using several tasks (6). Findings showed a facilitatory effect for both orthographic and phonological overlapping cognate words in the LDT, although the effect of phonological overlap was restricted to identical cognates. In contrast, in a language decision task (where participants had to decide about the language in which the word was presented), the orthographic similarity led to an inhibitory effect. This difference has been interpreted as suggesting that the emergence and the directionality of cross-language form similarity effects can depend on task demands as well as cognate type (identical vs. non-identical) (6). In another study, English-Spanish bilinguals were asked to name English and Spanish noncognate words as well as cognate words that varied in their degree of phonological and orthographic overlap (7). Naming responses were found to be faster for noncognates relative to cognates (an inhibition effect for cognates). Additionally, cognates with high orthographic and phonological overlap (O+P+) were named faster than cognates with high orthographic overlap but low phonological similarity (O+P-). In contrast, when the orthographic form of cognates was different (O-P+ and O-P-), the effects of phonology were not statistically reliable. These authors interpreted the results as evidence of an across-languages feedforward activation from orthography to phonology.

The evidence reviewed so far is consistent with a localist connectionist view of bilingual memory (6). According to this proposal, the cross-linguistic similarity of cognates leads to a greater semantic activation, since the associated meaning receives activation from two lexical representations rather than one, as it occurs with noncognates. However, the degree of semantic activation depends on the orthographic and phonological similarity of cognates due to the existence of inhibitory connections between lexical representations. Thus, the speed and accuracy of cognate reading depends on their cross-linguistic similarity. Nonetheless, this proposal is not very specific about the effects of phonological overlap with cognates with different levels of orthographic similarity. Moreover, as all abovementioned studies have used behavioral measures (based on the end point of word recognition), they cannot determine precisely the time course of phonological and orthographic code activation during visual word recognition. The ERPs technique is a good alternative, due to its high temporal resolution.

To our knowledge, no ERP study has investigated the interplay of phonological and orthographic overlap in the reading of cognate words. Nevertheless, previous evidence with homographs and homophones/pseudohomophones has suggested that orthographic and phonological differences between prime-target pairs do modulate early (before 200 ms) and late (around 350-550 ms) electrophysiological components (1, 8). Specifically, modulations between 50-100 ms after stimulus onset were typically interpreted as indicating that the initial access code for word recognition is phonological in nature (8). Later modulations (150-250 ms) were taken as an index of the activation of conflicting codes at the prelexical stage (9). In addition, the activation of phonological information was also observed in the time window between 350-550 ms (9, 10).

The present ERP study is the first to examine the interplay of phonology and orthography during the early stages of cognates processing. To this aim, we orthogonally manipulated the phonological and orthographic overlap between EP-English cognate words in a silent reading task combined with a masked priming paradigm. If phonology is computed early during visual word recognition, as strong phonological accounts predict (4), phonological differences between prime and target should modulate both early (before 200 ms) and late (around 400 ms) ERP components eliciting different waveforms in the translation and unrelated experimental conditions, especially when there is less graphemic overlap. This would also further support the localist connectionist account about cognate word processing and representation (6).

Method

Twenty-three undergraduate proficient bilinguals of EP (L1)-English (L2) from the University of Minho and a high school (mean age=23 years; SD=6.3) participated voluntarily in the study. All were right-handed, with normal or corrected-to-normal vision, and had no history of reading disabilities. Their linguistic background was assessed by the *Language History Questionnaire* (11), which shows that participants acquired the L2 at the age of 8.2 years (SD=1.9) on average. Their estimated English proficiency was 5.7 (SD=0.7) (in a 7-point Likert scale).

The material set consisted of 192 English target words: 96 cognates and 96 noncognates. Cognate words were assigned to each of four experimental conditions attending to their orthographic (O) and phonological (P) overlap: 24 O+P+ (*bomba*-BOMB), 24 O+P- (*cometa*-COMET), 24 O-P+ (*dança*-DANCE), and 24 O-P- (*laço*-*LACE*). We equated across conditions the number and position of shared letters across phonological primes and targets in order to reduce the possibility that our findings were due to influence of orthographic information. The conditions were matched in frequency, length, bigram frequency and orthographic/phonological neighborhood (all $p_s>0.14$) from N-Watch (12). Noncognate words (*limpo*-CLEAN) were selected as controls and randomly distributed across conditions for the purpose of a balanced design. Cognates and noncognates were also matched in frequency, length and bigram frequency (all $p_s>0.17$).

The degree of orthographic and phonological overlap was calculated based on objective and subjective measures. Regarding objective measures, the algorithm created by van Orden (13) was used to compute the orthographic similarity of cognate pairs. The score varied from 0 to 1, being of 0.77 (SD=0.06) for O+ pairs (O+P+/O+P-) and of 0.57 (SD=0.10) for O- pairs (O-P+/O-P-). Concerning the degree of phonological similarity, an expert on phonetics rated the phonological overlap according to the following criteria: 1) number of syllables the two words had in common; 2) position of the stressed syllable; 3) vowel quality of the stressed syllable and 4) preceding and following phonological context of the stressed syllable. The algorithm used to evaluate phonological similarity varied from 0 to 1, being of 0.73 (SD=0.14) for P+ translation pairs (O+P+ and O-P+) and of 0.34 (SD=0.18) for P- translation pairs (O+P- and O-P-). Self-rating of cross-linguistic similarity performed by the participants after the experiment correlated positively with the objective scores ($r_{sp}=0.81$, $p<.001$ and $r_{sp}=0.34$, $p<.01$ for orthographic and phonological similarity, respectively).

All cognate and noncognate English words were preceded by two types of EP primes: related words (equivalent translations) *vs*. unrelated words (neither in form or meaning) [e.g., *vasto* (vast)-BOMB]. Related and unrelated primes were matched in frequency (58.2 and 48, respectively), length (5.9 and 6, respectively) (P-PAL, 14), orthographic neighbors (2.9 and 2.2, respectively) and phonological neighbors (2.8 and 3.2, respectively) (PORLEX, 15). Two experimental lists were created by rotating the targets across conditions (either *bomba*-BOMB or *vasto*-BOMB). The stimuli are available at http://psico.fcep.urv.es/exp/colab/stimuli/.

Participants were tested individually in a quiet room and were randomly assigned to one of the two lists. Each list was repeated three times in three separate blocks to ensure stable electrophysiological data. Before starting the experiment, participants read the target words (randomly organized in a list) to minimize the potentially confounding repetition effects associated with seeing the stimuli repeatedly throughout the experiment (16).

Stimuli were presented by using the Presentation software (Neurobehavioral Systems, Inc.) on a 15” monitor set with a 60 Hz refresh rate. Each trial consisted of three visual events presented at the center of the screen: a 500 ms forward mask (#########) followed by the prime word in lower case for 47 ms, and immediately after by the target word in upper case until the participant’s response. The inter-stimuli interval was of 2000 ms. Participants were asked to read each target word silently as quickly as possible and to press the space bar on the computer keyboard to proceed. To ensure a comprehensive reading, they were informed that at the end of the experiment they would have to complete a free recall task. All participants reported not having seen any prime word.

While participants read the words, the EEG was collected using 32 Ag–AgCl electrodes mounted in an elastic cap (ActiCa), connected to a 32-channel QuickAmp amplifier (Brain Products GmbH, Munich, Germany). The EEG was acquired in a continuous mode at a digitization rate of 250 Hz, with a bandpass of 0.01 to 100Hz, and stored on a computer disk. Blinks and eye movements were monitored via electrodes placed at the external canthi of both eyes and electrodes placed at left supra- and infraorbital sites. Electrode impedances were kept below 5 Kohms at all electrode locations.

EEG data were processed offline using the BrainVision Analyzer package (Brain Products GmbH, Munich, Germany). Separate individual average waveforms were constructed to each target, with 152 ms baseline and 900 ms epoch, post-stimulus onset. Eye blink and movement artifacts were corrected by means of a procedure developed by Gratton, Coles, and Donchin (17).

Results

Behavioral data

Reaction times (RTs) more than 2.5 standard deviations above or below the mean for each participant and for each condition were excluded from the analysis (2.75% of the data).

ANOVAs based on the participant (F1) and item (F2) mean RTs were conducted based on a 2 (target type: cognate vs. noncognate) x 2 (Prime type: translation vs. unrelated) x 2 (Orthographic overlap -O: high vs. low) x 2 (Phonological overlap -P: high vs. low) x 2 (List: list 1, 2) mixed design. Mean RTs are presented in Table 1.

The results showed that cognates (571 ms) were read more slowly than noncognates (551 ms): $F1(1, 21)=18.14$, $p=0.000$, $\eta2=0.46$; $F2(1, 176)=32.66$, $p=0.000$, $\eta2=0.12$. Furthermore, the interaction effect between target type x prime type x P was obtained: $F1(1, 21)=11.45$, $p=0.003$, $\eta2=0.35$; $F2(1, 176)=17.78$, $p=0.008$, $\eta2=0.04$. This interaction reflected that responses for noncognate translation pairs were faster than responses for unrelated pairs, but only for one of two conditions randomly assigned to the different type of cognate words (p=0.012). Even when cognate pairs failed to show reliable effects of prime type, the difference between P+ and P- cognate pairs approached significance (p=0.079). That is, the greater the phonological overlap between prime and target, the longer the RTs. In addition, noncognate pairs were read faster than P+ (p=0.000) and P- (p=0.028) cognate pairs.

The analysis of the percentage of free recalled words showed a higher percentage of noncognate recalled words (19.81%) relative to cognates (10.3%) (t (44)=-4.42; p=0.000). The interaction between O and P was not significant: $F(3, 91)=0.33$; $p=0.81$.

ERP data

Trials containing excessive eye movements, blinks, muscle activity or amplifier blocking were rejected off-line before averaging (single-trial epochs with voltage exceeding +100/–100 μV were rejected from further analysis). Individual averages were only considered for further analysis if at least 70% of the segments available for a given condition passed the artifact rejection. Separate averages were calculated for each condition, after subtraction of the first 100 ms pre-stimulus baseline. Data were filtered offline with a low-pass filter of 12 Hz for graphical display only.

A one-way ANOVA on the mean number of segments in individual ERP averages for each condition revealed that there were no significant differences between conditions ($p>0.25$).

Based on visual inspection of ERP waveforms, three distinct components were identified: N100, P200 and N400 (see Figure 1). Mean amplitude was measured for each component in the following latency windows: N100 (60-160 ms); P200 (160-300 ms); N400 (300-500 ms).

Amplitude of each component was separately subjected to repeated-measures ANOVA based on the same RT design, with the exception of the inclusion of the region (Fz/3/4, Cz/3/4, Pz/3/4) as a within-subject factor. The Greenhouse-Geisser correction was applied to all repeated-measures with greater than one degree of freedom in the numerator. Significant interactions were followed by pairwise comparisons, with Bonferroni correction.

N100

The ANOVA yielded a significant effect of region ($F(2, 42) = 28.73$, $p=0.000$): N100 was more negative in parietal relative to both central ($p=0.000$) and frontal regions ($p=0.000$) (parietal=-1.22μV; central=-0.06μV; frontal=0.90μV). The interaction type of prime x region yielded significance ($F(2, 42)=5.34$; $p=0.020$), as translation pairs showed larger amplitudes than unrelated pairs in frontal and central regions ($p=0.025$ and $p=0.049$, respectively). Additionally, the interaction between target type x prime type x O x P x region approached significance ($F(2, 42)=2.69$, $p=0.08$). This interaction revealed differences in N100 amplitudes between translation cognate pairs and unrelated pairs that were greater for O-P+ conditions than for O-P- conditions. Indeed, N100 was more negative for O-P+ cognates relative to unrelated primes in frontal and central regions ($p=0.04$ and $p=0.022$, respectively) whereas for O-P- cognates the effect was reversed (larger amplitudes for unrelated pairs) and approached significance in parietal regions ($p=0.058$).

P200

A main effect of region was observed (F(2, 42)=37.45, p=0.000): P200 was larger in frontal relative to both central (p=0.002) and parietal (p=0.000) regions (frontal=3.06μV; central=2.15μV; parietal=-0.49μV).

The main effect of target type was also significant (F(1, 21)=5.181, p=0.033): P200 was larger for noncognates (1.63μV) relative to cognates (1.52μV). Additionally, the interaction between target type and prime type yielded significance (F(1, 21)=4.44, p=0.047), reflecting larger amplitudes for noncognates than for cognates when preceded by their translations (p=0.007).

N400

The ANOVA revealed a significant target type x prime type x O x P interaction (F (1, 21)=8.99, p=0.007). This interaction revealed a more negative-going N400 for cognate translation pairs from the O-P+ condition (0.06μV) relative to unrelated control pairs (0.59μV) (p=0.004) as well as relative to noncognate control pairs (0.64μV) (p=0.002). Moreover, N400 amplitude differences between O+P+ cognates and O+P- cognates reached significance (p=0.029), as O+P+ condition (0.04μV) were more negative than O+P- condition (0.41μV). Differences in N400 amplitude were also observed between noncognate translation pairs and unrelated pairs, but only for two out of four conditions randomly assigned to the different types of cognate words (p=0.018 and p=0.054).

Discussion

The interplay of orthographic and phonological overlap in visual cognate word recognition was the main focus of the present study. We addressed this issue by examining the influences of cross-language form overlap in the pattern of masked priming effects. The main findings can be summarized as follows. First, at the electrophysiological level, the relationship between prime and target modulated the N400 amplitude. The effects regarding cognate words were restricted to cognates with low orthographic overlap. Specifically, the O-P+ translation condition showed larger negativity than the unrelated control condition (i.e., a masked priming effect). Masked priming effects at this time window were also observed for noncognate words. Even when marginally significant, O-P+ and O-P- conditions within 100 ms post-target presentation showed earlier phonological modulations. Moreover, an effect of cognate status was observed at P200, as noncognates showed larger positivities relative to cognates. Second, at the behavioral level, data showed an inhibitory effect of cognate status. Noncognates were responded faster and were also recalled better than cognates. Besides, only the former showed masked priming effects on the RTs.

These results can be accommodated by the localist connectionist account, as it hypothesizes modulations in cognate recognition as a function of cross-linguistic similarity and task requirements. According to this model, after the presentation of an L1 cognate word prime, the graphemes activate the corresponding phonemes, which in turn, send activation to the whole-word representation. Then, all L1 and L2 words that overlap with the prime are activated, one of them being its equivalent translation in L2. Both representations send activation to the shared meaning representation, which in turn feeds back activation to the orthographic level.

The model postulates the existence of inhibitory connections between lexical representations. Thus, it is possible to think that when the two representations show a high phonological overlap, the lower orthographic overlap hampers the recognition of cognate target words due to lateral inhibition. This mechanism seems to depend on the combined effect of orthographic and phonological overlap, being possibly greater when the orthographic overlap is low, as strong phonological accounts predict (4). This interpretation is reinforced by the present data. Early (P200) and later (N400) ERP components are thought to reflect different stages of visual word recognition: automatic sublexical processing and lexico-semantic processing, respectively. Modulations around 200 ms and 400 ms have been identified in previous research as the electrophysiological markers of the cognitive processes underlying translation (18). Thus, while larger positivities to noncognate than to cognate words observed at the 200 ms time-window could be indexing an initial discrimination of stimuli as a function of their physical properties, N400 modulations could be reflecting interactions between levels of representation for O and P whole-words and semantics. Larger N400 amplitudes for the O-P+ condition would reflect a greater effort involved in forming links between these two levels. This occurs possibly due to the inhibitory connections between the two orthographic whole-word representations of cognate words. For noncognate words the lateral inhibition is minimal and thus they benefit from their semantic overlap, as was observed in the present study, both at an electrophysiological level (lower negativities for noncognates relative to cognates at 200 and 400 modulations) and at a behavioral level (lower RTs and better recall for noncognates relative to cognates).

This inhibitory pattern for cognates is consistent with what was observed in the study carried out with an overt naming task (7), which leads us to think that the mechanisms that underlie the reading of visual words (either silent or overt naming) might be similar, especially when phonological and orthographic similarity is taken into account. This is a striking result, since the findings obtained in most studies exploring cognate and noncognate word processing showed facilitation rather than inhibition. The only remarkable difference between these studies and the present work or the above-mentioned work (7) is that the former did not consider the phonological overlap of cognates. Further research is needed in order to explore the role of phonological overlap of cognate words across different tasks. However, even when the abovementioned study (7) showed an inhibition pattern for cognate words, the authors found that the degree of phonological overlap had an effect when orthographic similarity was high, just the opposite of what our ERP data revealed. It is worth noting that in that case the authors did not use the masked priming technique and presented a great number of identical cognates in comparison to ours, which presented none. The presence of identical cognates might have affected how orthography and phonology interacted, especially if there is a different representation for identical and non-identical cognates (a single vs. two symbolic representations), as the localist connectionist approach holds. In any case, the present findings support this theoretical approach (6), which states the importance of sublexical overlap for the distinctive processing of cognate words.

Taking the overall findings into account we can conclude that the hypothesis raised in the present study was only partially confirmed because we failed to find earlier phonological modulations. The marginal effects observed at the N100 time-window (mainly fronto-central) for O-P+ and O-P- conditions lead us to question if under certain conditions it would be possible to observe greater effects of priming at earlier stages of processing, following the predictions of strong phonological accounts, for example, by using cognate pairs with lower O overlap than those used in the present work. Note that a high percentage of pairs that were assigned to the O- condition (65%) varied only in two letters (e.g., *sena<u>do</u>*-senate). Further research is needed to confirm this idea.

In sum, the findings reported here have relevant implications for research on cognate word processing, since they provide evidence that phonological processes interacted with semantic activation during silent reading, and even more importantly, that these interactions are dependent on orthographic overlap of cognate words (being more evident for those conditions with less graphemic similarity). The findings fit well with a localist connectionist account (6), which emphasizes the form overlap of cognate words as the critical characteristic of the special status that these words appear to have in bilingual memory. In future research it will be critical to explore how cognate type (identical vs. non-identical) influences the activation of phonology and orthography.

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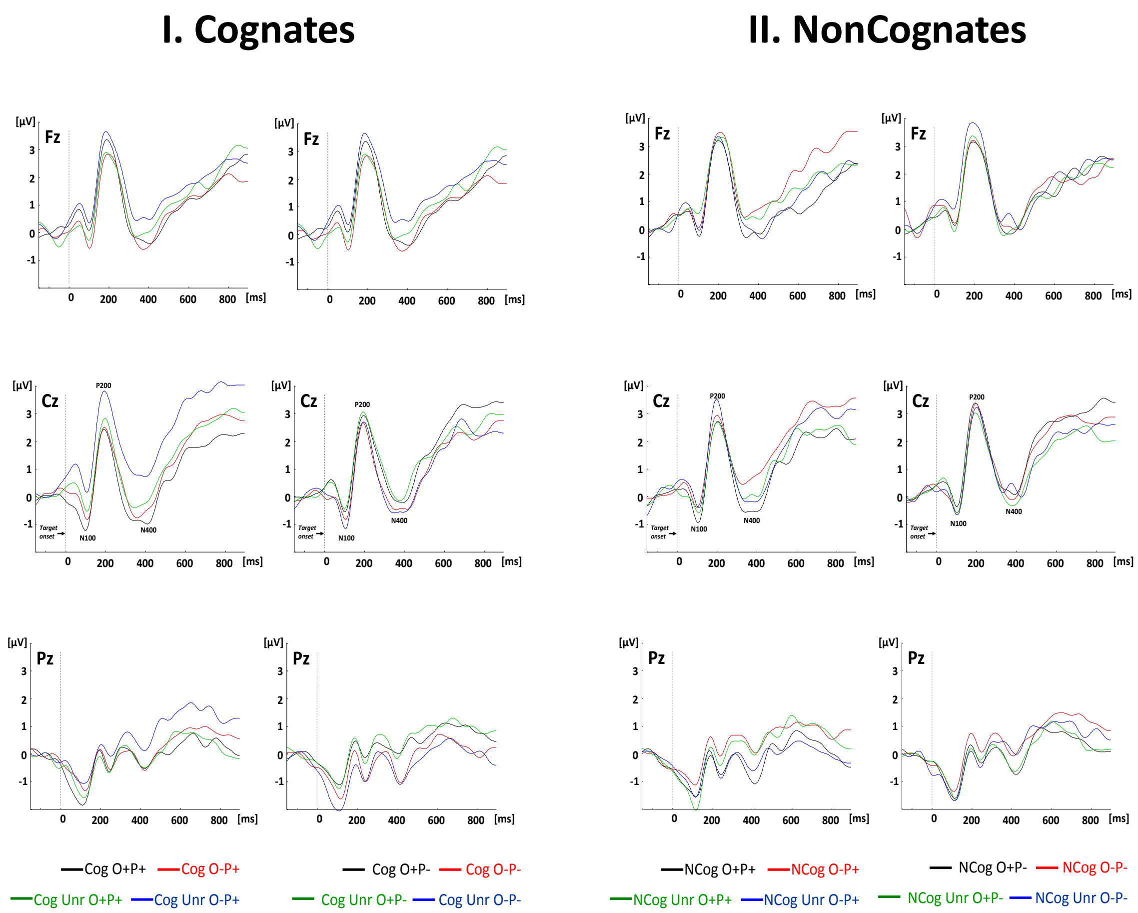
Captions

Figure 1. Grand averaged waveforms for cognate (I) and noncognate (II) words, as a function of prime type (translation vs. unrelated) and orthographic and phonological overlap. P+ (high phonology); P- (low phonology); O+ (high orthography); O- (low orthography); Unr (unrelated pairs).


I. Cognates
II. NonCognates
Fz
Cz
Pz
[µV]
[ms]
P200
N100
N400
Target onset
Cog O+P+
Cog O-P+
Cog Unr O+P+
Cog Unr O-P+
Cog O+P-
Cog O-P-
Cog Unr O+P-
Cog Unr O-P-
NCog O+P+
NCog O-P+
NCog Unr O+P+
NCog Unr O-P+
NCog O+P-
NCog O-P-
NCog Unr O+P-
NCog Unr O-P-

	Cognates		NonCognates	
	Translation	Unrelated	Translation	Unrelated
O+P+	569 (183)	557 (185)	535 (181)	552 (198)
O+P-	559 (187)	552 (183)	555 (195)	561 (176)
O-P+	574 (189)	563 (186)	537 (179)	547 (183)
O-P-	563 (197)	577 (193)	540 (191)	533 (193)

Table 1. Mean RTs (in ms) and SD (in parentheses) for cognate and noncognate words as a function of prime type (translation vs. unrelated) and orthographic (O) and phonological overlap (P).