Language context effects on interlingual homograph recognition: evidence from event-related potentials and response times in semantic priming*

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Dutch–English bilinguals performed a generalized lexical decision task on triplets of items, responding with "yes" if all three items were correct Dutch and/or English words, and with "no" if one or more of the items was not a word in either language. Sometimes the second item in a triplet was an interlingual homograph whose English meaning was semantically related to the third item of the triplet (e.g., HOUSE – ANGEL – HEAVEN, where ANGEL means "sting" in Dutch). In such cases, the first item was either an exclusively English (HOUSE) or an exclusively Dutch (ZAAK) word. Semantic priming effects were found in on-line response times. Event-related potentials that were recorded simultaneously showed N400 priming effects thought to reflect semantic integration processes. The response time and N400 priming effects were not affected by the language of the first item in the triplets, providing evidence in support of a strong bottom-up role with respect to bilingual word recognition. The results are interpreted in terms of the Bilingual Interactive Activation model, a language nonselective access model assuming bottom-up priority.

When reading a book in a particular language, bilinguals seldom become aware that many of the word forms they encounter may exist in the other language they know. For instance, all words in the Dutch sentence "Door spot leek die brave, dove arts rover met pet" are identical in orthographic form to English words that have radically different meanings; and yet, a bilingual reading this sentence will usually not be aware of that fact.[1]

However, although bilinguals may not become consciously aware of the existence of a word in both languages, empirical evidence collected in a large number of studies indicates that reading such words does nevertheless entail an early access to both mental lexicons in parallel (e.g., Altenberg and Cairns, 1983; Beauvillain and Grainger, 1987; Dijkstra, De Bruijn, Schriefers and Ten Brinke, 2000; Dijkstra and Van Heuven, 1998; Grainger and O'Regan, 1992; Nas, 1983; Tzelgov, Henik, Sneg and Baruch, 1996; Van Hell and Dijkstra, 1998; Van Heuven, Dijkstra and Grainger, 1998). Evidence in favor of nonselective access has been observed even under circumstances where only one of the languages is the target language, and is especially strong with respect to first-language effects on second-language target word processing. As a consequence, most researchers now adhere to this notion of initial "language nonselective access", and we will therefore also subscribe to this assumption in the present study.

At the same time, a limited number of studies have reported the absence of cross-linguistic effects for some types of stimulus materials and under particular experimental circumstances (e.g., Gerard and Scarborough, 1989; Dijkstra, Van Jaarsveld and Ten Brinke, 1998, Experiment 1; De Groot, Delmaar and Lupker, 2000, Experiment 2). For instance, lexical decisions by Spanish–English and Dutch–English bilinguals on interlingual homographs (words with identical orthography but different meanings across languages, e.g., Dutch–English ANGEL, meaning "sting" in Dutch) did not differ significantly in speed and error rates from those to exclusively one-language control items. Such results

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[1] The English translation of the Dutch sentence is: "By mockery that honest, deaf doctor resembled robber with cap."

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suggest that the effects of the non-target language on target identification were suppressed or washed away by the time the response was made, or that factors working in opposite directions cancelled each other (Dijkstra, Grainger and Van Heuven, 1999).

Of course, in order to arrive at a correct and contextually appropriate interpretation of an interlingual homograph, the bilingual reader must at least at some point in time select the most likely lexical candidate (as our introductory example clearly shows). In a recent study involving the recognition of items in mixed lists of English and Dutch words, it was found that the initially nonselective activation of interlingual homographs from both languages was followed by a late selection process of the homograph's reading in the relevant target language (Dijkstra, Timmermans and Schriefers, 2000). Thus, given that the appropriate reading of the homograph was selected only relatively late during the recognition process, there is the possibility that under particular context conditions lexical selection might be speeded by suppression of lexical candidates from the nontarget language (cf. similar assumptions for language production as made by Kroll, Dietz and Green, 2000; Green, 1998). Consider the recognition of the Dutch–English word form ANGEL in an English or a Dutch language context. The language of the items in a sentence or stimulus list preceding the word ANGEL might determine which of its readings is quickly suppressed (Dijkstra et al., 1998; Green, 1998). For instance, upon presentation of ANGEL in a Dutch context, the English and Dutch orthographic representations of the item would initially both become activated, but the irrelevant English reading would be suppressed so quickly that its associated meaning never becomes active to any considerable (or measurable) extent. In other words, lexical access would be nonselective at the form (orthographic) level but selective at the semantic level.

Alternatively, lexical access might always be nonselective with respect to both orthography and semantics, and a prior word or sentence would be incapable of suppressing the semantic activation of the various readings of the homographs. In this view, the ultimate selection of a lexical candidate would involve a decision process operating on the output of the identification system and contextual factors would not change the recognition process itself (i.e. the activation patterns arising on the basis of the lexical input).

In this paper we will study this issue with respect to the recognition of interlingual homographs such as ANGEL. We will, first, investigate if activation of the meaning of an interlingual homograph in the second language (L2) can be demonstrated in response times (RTs) and event-related potentials (ERPs), and, second, whether the observed activation can be reduced by varying the language of the item immediately preceding the homograph.

Theoretical background

Dijkstra et al. (1998) performed a series of experiments indicating that lexical access is initially language nonselective. Dutch bilingual participants performed two English lexical decision experiments including English–Dutch homographs as well as a matched set of control words that were only English. In the first experiment, which did not contain any non-English words, RTs to homographs and controls were equally fast. However, when in the second experiment Dutch words were added to the experimental list that had to be treated as nonwords and required a ''no''-response, strong inhibitory effects were obtained for the homographs. The participants now apparently had difficulty making a ''yes''-decision to an item that had both an English and a Dutch reading. Furthermore, the RTs to homographs in this experiment were affected by the relative frequency difference between the two readings: RTs were slower for homographs with a high frequency of the Dutch reading (such as RAMP, Dutch for ''disaster'') than for homographs with a low frequency of the Dutch reading (such as SAGE, meaning ''legend'' in Dutch). In sum, when the list included target words from both languages, clear support for language nonselective access was obtained.

In a follow-up study, Dijkstra, De Bruijn et al. (2000) showed that it was indeed the presence of the Dutch words that affected the participants' performance. In an English lexical decision experiment they introduced Dutch words only in the second half of the experiment. The results in the two halves of the experiment replicated those of Dijkstra et al. (1998) in their Experiments 1 and 2. No difference was obtained between interlingual homographs and corresponding control words in the first half of this experiment (cf. Experiment 1 above), while inhibition effects arose in the second half of the experiment (cf. Experiment 2 above). Because the inhibition effects for the homographs were already very strong immediately after the first exclusively Dutch item was introduced, it is evident that under these circumstances local context words were able to exert clear effects on homograph processing.

While Dijkstra et al. (1998) found evidence for language nonselective access, they did not discuss in detail whether the obtained effects were basically orthographic or semantic in nature. More direct

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evidence bearing on this issue has recently been collected by De Moor and Van Heste in collaboration with Marc Brysbaert (De Moor, 1998, reported by Brysbaert, 1998; Van Heste, 1999). De Moor (1998) also found no RT difference between interlingual homographs and controls in an English lexical decision task with Dutch–English bilinguals similar to Experiment 1 by Dijkstra et al. (1998). However, if on the trial following the homograph the English translation of the Dutch reading of the homograph was presented, a translation priming effect of 11 ms was observed, which reached significance in the item-analysis. In a replication of this experiment with different stimulus materials, Van Heste (1999) observed a reliable 35 ms difference between translation and control trials. Thus, if FIRE was preceded by BRAND (meaning "fire" in Dutch), faster RTs occurred than after an unrelated word. The translation priming effect suggests that, although it did not become apparent in the lexical decision time to the English reading of the homograph, its Dutch reading had indeed been activated.

Finally, in a recent study, Dijkstra, Grainger and Van Heuven (1999) showed that in a lexical decision task with L2 target words, interlingual homographs activate their form and their meaning representations in both L1 and L2. In sum, the available evidence from RT studies indicates that both semantic representations associated with an interlingual homograph are activated. To what extent the surrounding language context is able to modulate these effects is still unclear.

In this article, we use the N400 – that is, an ERP component – alongside RT measures to investigate how context affects the processing of interlingual homographs. It has been established that the N400 is especially sensitive to semantic processing (see Kutas and Van Petten, 1994; and Osterhout and Holcomb, 1995, for reviews). A distinction needs to be made between the presence or absence of the N400 as opposed to modulations in N400 amplitude. Each open-class word evokes an N400, so that the elicitation of this component is a default response to words. Relevant for the present research is that N400 amplitude is very sensitive to semantic relations between words, both in word–word and in sentential contexts. In particular, N400 amplitude is smaller when a word is preceded by a semantically related word (e.g., LION – TIGER) than when it is preceded by an unrelated word (e.g., NOSE – TIGER). This difference in amplitude is referred to as the *N400 priming effect*.

Based on previous work we assume that the N400 priming effect mainly – if not exclusively – reflects post-lexical processes that arise from integrative mechanisms and, in certain situations, expectancy (see for a discussion of the integration view Chwilla, Hagoort and Brown, 1998; Chwilla, Kolk and Mulder, 2000). Specifically, we assume that N400 reflects a higher-level integration process that operates on several kinds of lower-level information, such as lexical-semantic, syntactic and pragmatic information. Modulations in N400 amplitude appear to reflect the ease with which these different knowledge sources are integrated with the preceding context, be this a word or a sentence fragment. The better a new piece of information fits into the ongoing representation, the easier the lexical integration process and the smaller the N400 amplitude will be.

The rationale for combining the ERP- with the RT-technique was two-fold. First, ERPs provide a continuous multidimensional measure (with a temporal resolution at the level of milliseconds). Therefore, ERPs might provide a more detailed picture about the way in which context affects the processing of interlingual homographs than the measurement of RTs alone. Second, we suppose that the N400 only reflects a subset of the processes reflected by RTs. Particularly, we assume that RTs reflects spreading activation, post-lexical integration, and decision processes whereas N400 more exclusively indexes post-lexical integration processes. Therefore, the combination of these two measures may help to establish the relative contribution of these different processes to the semantic priming effects elicited by interlingual homographs.

To date, almost all ERP studies have investigated monolingual language comprehension (but see Ardal, Donald, Meuter, Muldrew and Luce, 1990; Weber-Fox and Neville, 1996). In our study, we extend the ERP technique to the bilingual domain to assess whether the L2 semantic representation of an interlingual homograph is automatically activated during word reading. More specifically, we test whether the amount of such activation is context-dependent, i.e., depends on whether the interlingual homograph is preceded by a word from the participant's native language (Dutch in our case) or by a word from the participant's second language (English in our case). With this aim we employ a *semantic priming paradigm* in which participants respond to triplets of items: two simultaneously presented items followed by a third item. Previous monolingual work from our laboratory has shown that these presentation conditions yield robust RT and N400 priming effects in lexical decision (Chwilla and Kolk, 1998). Our bilingual participants will perform a variant of the Generalized Visual Lexical Decision (GVLD) task on the triplets. The GVLD task has been successfully used before in a study by Dijkstra et al. (1998) on the recognition of

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interlingual homographs presented in isolation. In that study, it led to facilitation effects for such items relative to one-language control items, indicating that both readings of the interlingual homographs are activated in parallel in this task. In the present study, we will extend the GVLD task to triplets of items. Participants have to respond "yes" if the three items in a triplet are a mix of correct Dutch and/or English words, and "no" if one or more items is not a word in either language. They are informed that both types of triplets can contain words from both languages. On each trial participants first see two words, positioned to the left and right of a fixation cross, referred to as Items 1 and 2. On critical trials, Item 1 is either a Dutch or an English word, and Item 2 is an interlingual homograph. Because the language of Item 1 is meant to potentially bias the activation of the interlingual homograph toward its Dutch or English reading, it will also be referred to as language prime. Items 1 and 2 are then replaced by an English word (Item 3) that is either semantically related or unrelated to the English reading of the homograph. This third item is always unrelated to the Dutch reading of the interlingual homograph. In the examples below, the three words comprising a triplet are presented in the following order: Item 1 (language prime) – Item 2 (homograph) – Item 3 (target). This paradigm allows a test of the following hypotheses.

First, we will assess whether the semantics of the English readings of the homographs is activated by comparing test triplets like HOUSE – ANGEL – HEAVEN to matched control triplets such as HOUSE – ANGEL – BUSH. In the first triplet, there is a semantic relationship between the English reading of ANGEL and HEAVEN, while no such relationship exists in the second triplet. Whether the English semantic representation is activated can be inferred from the presence of RT and N400 priming effects for related as opposed to unrelated items.

Second, we will examine the extent to which the activation of the English reading of the interlingual homographs is context-sensitive. By preceding the homograph by either a Dutch or an English word (language prime), its reading should become biased towards Dutch or English. Examples are ZAAK – ANGEL – HEAVEN versus HOUSE – ANGEL – HEAVEN. If the language prime affects the processing of the interlingual homograph, then different RT and/or N400 priming patterns should occur for the Dutch language prime triplets relative to the English language prime triplets.

Method

Stimulus selection

The stimulus materials for the experiment were selected on the basis of several pilot studies. As a first pilot study, ten native Dutch speakers were asked to generate English words that were semantically related to the English readings of 85 interlingual homographs. A second pilot study was conducted to obtain words, unrelated to the English and Dutch readings of the homographs, that were matched with respect to their RTs to the semantically related words selected previously. Twenty participants performed an English lexical decision task on isolated target items, consisting of 368 items of three types: 85 English words related to the homographs, 99 English words unrelated to the homographs, and 184 nonwords. The participants decided as quickly and as accurately as possible whether each presented letter string was a correct English word or not. Mean RTs were computed for all items, showing faster responses to words than to nonwords (559 ms versus 616 ms). On the basis of its mean RT, each item that was semantically related to the English reading of the homograph was matched with a word from the set of unrelated words. This procedure, which has been applied before by Chwilla et al. (1995, 1998), resulted in a selection of 51 matched word pairs. For the remaining 34 semantically related items, no such RT matching with unrelated words was possible. These items were matched with the nonrelated words in terms of word frequency and number of letters. Thus, as a result all 85 words that were semantically related to the interlingual homographs were matched with 85 unrelated words (henceforth called control words) on the basis of either RT or word frequency.

A third pilot study was conducted to select those interlingual homographs that would induce priming effects on the semantically related items from the previous pilot study. Twenty participants were presented with pairs of items and had to decide whether the second item of each pair was an English word or not. The first item of each pair was always one of the 85 interlingual homographs, followed directly by its semantically related word, the matched semantically unrelated word or a nonword. In total, the participants saw 340 item pairs, because each interlingual homograph was presented twice as a prime in combination with nonwords as targets and twice with words (semantically related or not) as targets. Participants were explicitly instructed that all items, including the primes, would be either correct English words or nonwords. This was done to ensure that participants would base their response on the English

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reading of the interlingual homographs. Means were computed for all target items, showing faster responses to words than to nonwords (765 ms versus 839 ms). A priming effect of at least 15 ms between semantically related targets and their matched unrelated targets was used to separate item pairs that resulted in semantic priming from those that did not. This selection criterion led to a selection of 52 semantically related word pairs. All 52 homographs in these pairs were form-identical for English and Dutch, and their frequencies in both languages covered a wide range. These item pairs were used as the critical items in the following experiment.

Participants

Twenty right-handed Dutch native speakers (5 males and 15 females) participated in the experiment. Their age ranged from 21 to 26 years. All participants had been studying at the University of Nijmegen for at least two years. They had eight or more years of experience with the English language and were paid for their participation. Hand dominance was assessed with an abridged Dutch version of the Edinburgh Inventory (Oldfield, 1971). All participants had normal or corrected-to-normal vision. None of them had taken part in the pilot studies.

Design

Participants were tested individually in a sound-attenuating and electrically shielded chamber. The stimuli consisted of 312 triplets consisting of nonwords and/or words, presented in upper-case black letters on a white background at moderate contrast at the center of a 15-inch monitor (within a window of 8 by 2 cm; approximately 3.0 x 0.8 degrees of arc). The monitor was placed at a distance of approximately 100 cm from the participants. The second and the third item of the critical triplets consisted of the 52 semantically related (e.g., ANGEL – HEAVEN) and 52 unrelated matched item pairs (e.g., ANGEL – BUSH). As their first item, 26 of the semantically related and 26 of the unrelated triplets contained a highly frequent English language prime (e.g., HOUSE – ANGEL – BUSH), and the other 26 a highly frequent Dutch language prime (e.g., NEUS – ANGEL – BUSH). Next to the critical triplets, 52 filler triplets were added, containing both English and Dutch words in all three positions. Across the experiment as a whole, the proportion of exclusively English to exclusively Dutch words was about 2:1. Finally, 156 filler triplets were added that contained one nonword (in 90% of the cases) or two nonwords (in 10% of the cases) that were derived from English or Dutch words by substituting one or two letters. These nonwords could occur at any position within the triplet (i.e. 30% of the nonwords occurred as Item 1, 40% as Item 2 and 30% as Item 3).

Word and nonword triplets were randomly included in a stimulus list with the restriction that no more than three consecutive trials could be of the same response type (“yes” or “no”). Each participant saw each interlingual homograph twice, once combined with a related word and once with an unrelated word. In these two cases, the language primes preceding the interlingual homograph were words that were both English or both Dutch and were matched in frequency. For example, NOSE – ANGEL – HEAVEN (related condition with English prime word) would be followed by BOOK – ANGEL – HORSE (unrelated condition with English prime). Thus, the only test items that occurred twice in each experimental session were the interlingual homographs. Half of the interlingual homographs were preceded by English language primes, the other half by Dutch language primes. To ensure a completely counterbalanced design, the resulting four blocks of triplets (with related and unrelated items following the interlingual homographs, and with Dutch or English language primes preceding them) were incorporated in four different lists according to a Latin square.

Apparatus: electrophysiological recording

The EEG was recorded from 13 tin electrodes mounted in an elastic electrode cap (Electrocap international). Referenced to the left mastoid the electrode positions included standard International 10–20 system locations at frontal sites (F7 and F8) and three midline sites: frontal (Fz), Central (Cz) and parietal (Pz). Eight electrodes were placed at nonstandard positions previously found to be sensitive to language manipulations (e.g., Holcomb and Neville, 1990): left and right anterior temporal sites (LAT and RAT: 50% of the distance between T3/4 and F7/8), left and right temporal sites (LT and RT: 33% of the interaural distance lateral to Cz), left and right temporoparietal sites (Wernicke’s area and its right hemisphere homologue, LTP and RTP: 30% of the interaural distance lateral to a point 13% of the nasion–inion distance posterior to Cz), and left and right occipital sites (OL and OR: 50% of the distance between T5/6 and O1/2). Electrode impedance was less than 3 Kohms. Because eye movements distort the EEG recording, the electro-oculogram (EOG) was recorded. Vertical EOG was recorded bipolarly by placing an electrode above and below the right eye. The horizontal EOG was recorded bipolarly via

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a right-to-left canthal montage. EEG and EOG signals were amplified (time-constant = 8 sec, band-pass = .02–30 Hz). All physiological signals were digitized on-line with a sampling frequency of 200 Hz using a 16 bit A/D converter.

Procedure

To avoid a distortion of the EEG recording by motor artifacts, participants were asked to move as little as possible. Participants pressed a button with their right index-finger as quickly and accurately as possible if all three letter strings were existing English or Dutch words, and with their left index-finger if they were not. If the response was incorrect, the Dutch word "FOUT" (which means wrong) appeared on the screen for 2 sec.[2] Each trial started with the presentation of a fixation cross at the center of the screen for 500 ms. Next, Items 1 and 2 appeared simultaneously, Item 1 to the left of this fixation cross and Item 2 to the right. These two items and the fixation cross disappeared after 400 ms. They were immediately followed (ISI = 0 ms) by the presentation of Item 3, displayed at the center of the screen for 400 ms. Response latencies and ERPs were measured from the onset of Items 1 and 2. The stimulus set was divided into three blocks. Blocks lasted about 11 minutes and were separated by short breaks. A short practice session of 32 trials preceded the experimental session. Participants were trained not to make eye movements before the onset of Items 1 and 2 until approximately 2 sec after the button press and to fixate on the cross in the center of the screen.

Analysis of the RT data

The data from one critical triplet and its matched control triplet were excluded from further analyses because of an excessive error rate (> 50%). We further removed the data from three other critical triplets and their matched control triplets because the interlingual homographs they contained were reported to be unknown by many participants. Note that a lexical decision to an interlingual homograph was only required in the experiment and not in the pilot studies. Therefore, it was not clear in advance whether all homographs were known to the participants or not. Leaving out these triplets did not affect the matching between test and control triplets. For the remaining data points, response times outside the range of two standard deviations from a participant's and item's mean were considered outliers. Outliers and incorrect responses (15.6% of the data, 10.8% for word triplets and 20.3% for nonword triplets) were excluded from further analysis. Mean RTs, standard deviations and error percentages for the different conditions are presented in Table 1.

Table 1. *Mean response times (RTs), standard deviations (SD), and error percentages as a function of Language Prime and Relatedness*

Language Prime	Related			Unrelated			Overall		
	RT	SD	Errors	RT	SD	Errors	RT	SD	Errors
English	1120	141	7.5	1156	161	7.1	1138	149	7.3
Dutch	1125	145	9.2	1155	154	9.6	1140	149	9.4
Overall	1122	140	8.3	1156	156	8.3			

RTs were measured from the onset of Items 1 and 2. To obtain the RTs from the onset of Item 3, subtract 400 ms from the RT values (e.g., 1120 ms becomes 720 ms).

The RT data were subjected to several analyses of variance (ANOVA) with the factors Relatedness (related/unrelated) and Language Prime (English/Dutch). ANOVAs were conducted by participants only, because the stimulus materials form an almost exhaustive sample of all possible items.[3]

An ANOVA was conducted on the trials of critical triplets consisting of words only, which yielded a main effect for Relatedness [$F(1,19) = 29.34$, $p < .001$]. Mean RTs for related triplets (1122 ms) were faster than for unrelated ones (1156 ms). The factor Language Prime did not result in a main effect [$F < 1$]. More importantly, there was no interaction between Relatedness and Language Prime [$F < 1$].

Because we had decided at the outset to test for the effects of different language primes, we also performed separate ANOVAs for the two levels of language primes. An ANOVA for the English language prime conditions yielded a main effect for Relatedness [$F(1,19) = 12.58$, $p < .01$]. Mean RTs for related triplets with an English language prime (1120 ms) were faster than for unrelated triplets with an English language prime (1156 ms). An ANOVA on Dutch language primes also resulted in a main effect for Relatedness [$F(1,19) = 17.98$, $p < .001$]. Mean

[2] Different ERP components, such as slow negative potentials and P3 are affected by feedback (Johnson, 1988). In the present experiment only incorrect responses were followed by a feedback signal. Because incorrect trials were excluded from later analysis, we consider it unlikely that the presentation of feedback on incorrect trials affected the ERPs on correct trials.

[3] Specifically, in the present experiment the item-based statistic is *not* considered to be informative for the following reasons. The F ratio is probably ill-formed (and negatively biased) because (a) there is no sense in which items were randomly selected and (b) the sizes of treatment effects almost certainly differed in the population. For discussion see Wike and Church (1976).

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RTs for related triplets with a Dutch language prime (1125 ms) were faster than unrelated triplets with a Dutch language prime (1155 ms). Separate analyses on the related and unrelated conditions including the factor Language Prime were not significant for both related items [$F < 1$] (1120 ms and 1125 ms) nor for unrelated items [$F < 1$] (1156 ms and 1155 ms).

Error analyses

Next, an ANOVA was conducted on the error data presented in Table 1 using the factors Relatedness and Language Prime. No main effects of Relatedness [$F < 1$], Language Prime [$F(1,19) = 1.76$, $p = .20$], or any interaction between the two factors [$F < 1$] were observed. The separate ANOVAs for the two language primes did not yield effects of Relatedness either ($Fs < 1$).

Analysis of the effect of nonword position on RT

In general, word triplets were reacted to more slowly than nonword triplets, as shown in a one-way ANOVA with Lexical Status as a factor (word triplets: 1146 ms, nonword triplets: 1121 ms, $F(1,19) = 8.04$, $p < .05$). This result suggests that participants responded "no" as soon as they detected a nonword. A further one-way ANOVA showed that RTs to triplets containing one nonword were affected by the position of the nonword in the triplet. Trials in which Item 1 was a nonword resulted in faster mean RTs than those in which Item 2 was a nonword (1047 ms versus 1097 ms) [$F(1,19) = 12.45$, $p < .01$].[4] From this we can conclude that participants read the triplets from left to right. This is important because under these circumstances the language prime (Item 1) can in principle affect processing of the interlingual homograph (Item 2).

Analyses of ERP data

EEG and EOG records were examined for artifacts and for excessive EOG amplitude during the epoch from 100 ms preceding Items 1 and 2 to 1600 ms after the onset of Item 3. Only trials in which correct responses were given and in which no other artifacts occurred were analysed (EOG criterion for rejection: $< 100\ \mu V$). ERPs were averaged time locked to Items 1 and 2, relative to a 100-ms pre-item baseline. To allow a closer examination of the time course of potential differences in brain response as a function of relatedness and language prime, the ERPs were analysed in the following way. For each participant, the mean amplitude of 100-ms epochs (i.e., the mean of 20 sample points) for the experimental conditions was computed starting 100 ms after the onsets of Items 1 and 2 and extending to 1200 ms (e.g., the first epoch included the interval of 0 to 100 ms and was a mean of the EEG amplitude at 5, 10, 15, 20, 25, . . . up to 100 ms, etc.). The mean amplitudes for each of these epochs were then entered into a three-way analysis of variance (ANOVA) with repeated measures on Relatedness (related versus unrelated to the English reading of the homograph), Language Prime (English versus Dutch) and Electrode (13 levels). To further explore the scalp distribution of the ERP effects two supplementary analyses were conducted: one with a three-level midline-electrode factor (Fz, Cz, Pz) and the other with a hemisphere (left, right)-by-lateral electrode (F7/8, LAT/RAT, LT/RT, LTP/RTP, OL/OR) design. To control for an increase in Type I error in within-participants tests, the degrees of freedom of F-tests with more than 1 degree of freedom in the numerator were adjusted by means of the estimated Greenhouse and Geisser (1959) coefficient epsilon. The stated degrees of freedom are uncorrected to aid the reader in interpreting our statistical design.

Results

Grand average waveforms for the English language prime and the Dutch language prime condition are presented in Figures 1 and 2 respectively, in which related and unrelated items are superimposed. Note that negativity is plotted upwards. Items 1 and 2 are presented at time point zero and Item 3 is presented at 400 ms. The averages for the English language prime condition were based on 416 trials for the related and on 412 trials for the unrelated condition. The averages for the Dutch language prime condition included 412 trials for the related and 405 trials for the unrelated condition. Each condition could maximally include 520 (26 homographs x 20 participants) trials. Inspection of the waveforms across the whole stimulus sequence displayed in Figures 1 and 2 reveals that the waveforms for the two language conditions look quite similar. Items 1 and 2 elicited a small negativity (N1), which was followed by a positive deflection showing largest amplitudes at the midline electrodes and peaking at about 200 ms (P2). Note that the early ERP components elicited by Item 3 are less clearly visible in the waveform. This is likely due to an overlap in processing of Items 1 and 2 with the processing of Item 3. The P2 elicited by Items 1 and 2 was followed by a sequence of two

[4] Triplets containing a nonword as Item 3 were not considered in this analysis, because this item was presented later than Items 1 and 2.

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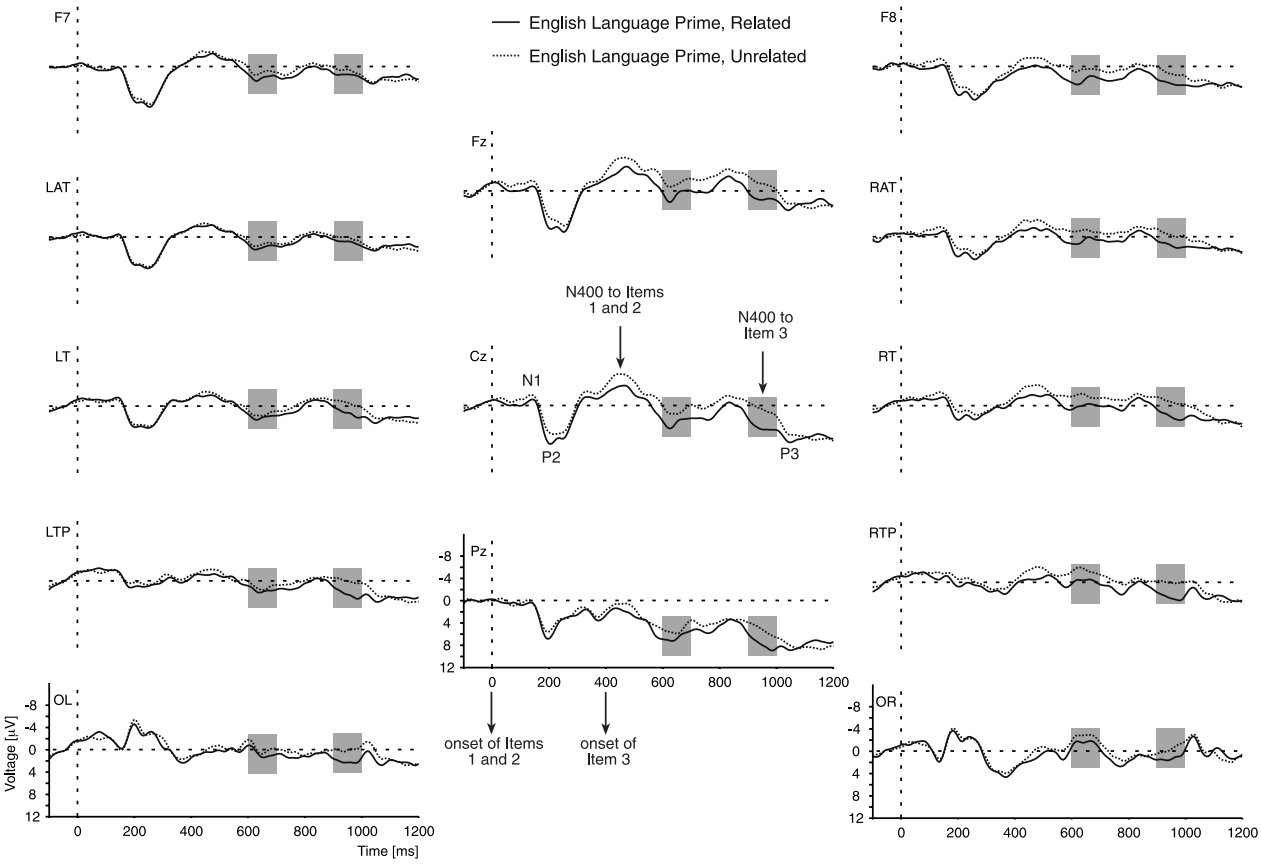


Figure 1. Grand ERP averages over participants (n = 20) for the English language prime condition time-locked to the onset of Items 1 and 2 separately for related (solid line) and unrelated triplets (dashed line). Note that the entire Item 1, Item 2, and Item 3 epoch is presented. This allows visual inspection of the waveforms across the whole processing sequence. Waveforms are shown from electrode sites on the midline (Fz, Cz, and Pz), and over left and right frontal (F7, F8), anterior temporal (LAT, RAT), temporal (LT, RT), temporoparietal (LTP, RTP), and occipital sites (OL, OR). The shaded areas indicate the two windows in which significant relatedness effects were present.

relatively long-lasting negative-going waves that were most pronounced at the midline. The first negative-going wave followed the presentation of Items 1 and 2 (time-window: 400–600 ms measured from onset of Items 1 and 2), and the second negative-going wave followed the presentation of Item 3 (time-window: 800–1000 ms, corresponding to the 400–600 ms epoch measured from Item 3 onset). The amplitude of the second negative-going wave was modulated by Relatedness showing smaller amplitudes for semantically related items as opposed to unrelated items. This Relatedness effect was present at most electrodes but appeared to be smaller at anterior sites (F7, LAT, F8, RAT). Based on the timing of these negative-going waves relative to word onset and the sensitivity of the second negative-going wave to semantic relatedness, we interpret these negative-going waves as N400s. The N400 to Item 3 was followed by a posterior distributed positive-going wave, peaking around 1050 ms (the P3). A P3 is elicited in any task that requires a binary decision (e.g., Johnson, 1988). Because our participants made binary lexical decisions, the N400 priming effect was followed by a P3.

Because very similar patterns of results were obtained for the overall, the midline and the lateral time-course analyses, and to reduce the total number of analyses, only the results for the overall ANOVAs will be reported. The overall time-course analyses presented in Table 2 revealed main effects of Language Prime and Relatedness, but for none of the intervals was there any interaction between Language Prime and Relatedness (all $Fs < 3$). The effect of Language Prime was significant from 0 to 200 ms and for three consecutive time-windows from 300 to 600 ms. The main effects of Language Prime indicate that mean amplitudes were more negative for the Dutch than the English language prime condition. Note that

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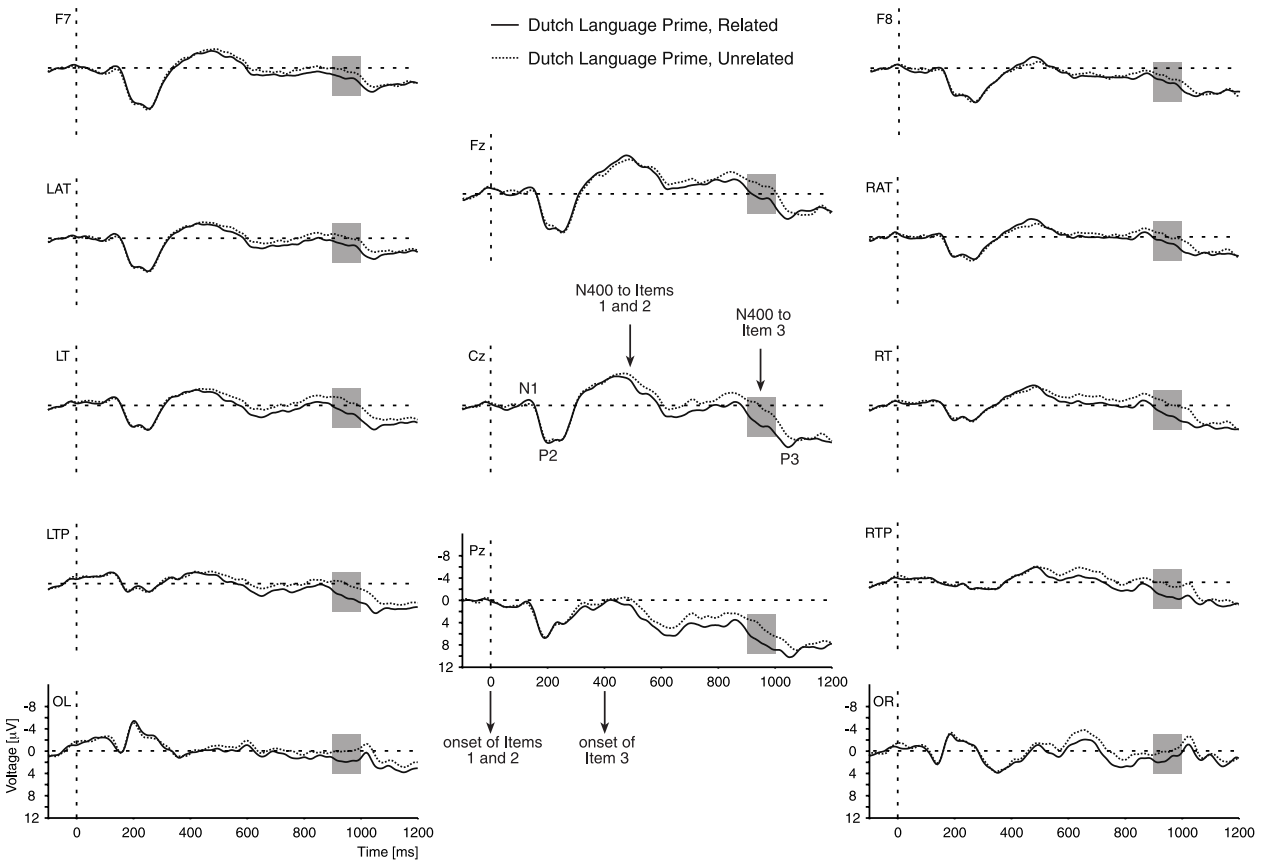


Figure 2. Grand ERP averages over participants (n = 20) for the Dutch language prime condition time-locked to the onset of Items 1 and 2 separately for related (solid line) and unrelated triplets (dashed line). The shaded area indicates the window in which a significant Relatedness effect was present.

the effect of Language Prime occurred already within the first 100 ms following the onset of Items 1 and 2. The time-course analyses yielded relatedness effects in six consecutive time-windows starting at 500 ms and extending to 1100 ms. The onset of the relatedness effect measured from Item 3 onset (significant effects were obtained in the 100–200 ms epoch after Item 3 onset) should also be considered as rather early, because it precedes the onset of monolingual N400 priming effects reported in the literature (e.g., Kutas and Van Petten, 1994).

It is unclear what these early ERP effects reflect. Regarding the early effects of Language Prime we consider it highly unlikely that they reflect aspects of lexical processing, because they even precede the N1 component typically considered to mainly reflect the processing of the mere physical aspects of a stimulus. A more likely explanation is that these early effects reflect item differences. Because necessarily different sets of Items 1 had to be used for the two language prime conditions, we cannot entirely rule out the possibility that these differences arise from item variance. The presence of early Language Prime effects preceding the presentation of Item 3 causes differences in baseline. Allowing these pre-Item 3 differences to enter the post-Item 3 epoch induces an extra source of error and therefore has to be avoided.

One possibility to correct for these early ERP effects is to time-lock the ERPs to the onset of Item 3. Therefore, a second set of time-course analyses was conducted in which the ERPs were averaged time-locked to Item 3 using a 100 ms pre-Item 3 baseline. This procedure "forces" the waveforms to align before Item 3 onset, thereby reducing the impact of ERP differences preceding it. The results of these analyses, summarized in Table 3, show that this procedure was effective in eliminating early Language Prime effects. Language Prime effects were now only observed in two late windows (1000–1200 ms). In contrast, relatedness effects still occurred in an early window (from 500 to 800 ms) and in a later window (from 900 to 1000 ms), which corresponds to the 500–600 ms window measured from the onset of Item 3. Again, for none of the intervals did we obtain

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Table 2. *Time-course analyses for the overall analyses including both levels of language prime and all thirteen electrodes using a pre-Items 1 and 2 baseline*

Window	Relatedness	Language Prime	Relatedness x Language Prime
	$F(1,19)$	$F(1,19)$	$F(1,19)$
0–100	< 1.5	9.34 **	< 1
100–200	< 1.5	5.03 *	< 1.5
200–300	< 1.5	< 2	< 1
300–400	< 1	7.25 *	< 1
400–500	4.00	5.56 *	2.56
500–600	7.85 *	8.50 **	< 1
600–700	10.21 **	3.10	< 1
700–800	9.63 **	< 2.5	< 1
800–900	7.48 *	< 1	< 1
900–1000	16.71 **	< 1	< 1
1000–1100	5.25 *	3.29	< 1
1100–1200	< 1	< 1.5	< 1.5

Significance levels: ** $p < .01$, * $p < .05$

Table 3. *Time-course analyses for the overall analyses including both levels of language prime and all thirteen electrodes using a pre-Item 3 baseline*

Window	Relatedness	Language Prime	Relatedness x Language Prime
	$F(1,19)$	$F(1,19)$	$F(1,19)$
400–500	< 2	< 1	< 2
500–600	5.01 *	< 1	< 1
600–700	6.96 *	< 1	< 1
700–800	5.35 *	< 1	< 1
800–900	4.02	3.81	< 1.5
900–1000	13.21 **	< 2	< 1
1000–1100	3.49	12.75 **	< 1
1100–1200	< 1	7.17 *	< 2.5

Significance levels: ** $p < .01$, * $p < .05$. To obtain the time-windows relative to the onset of Item 3, subtract 400 ms from the given window range (e.g., 800–900 ms becomes 400–500 ms).

any interaction between language prime and relatedness (all Fs < 2.5; see Table 3).

Because the evaluation of the ERPs for the two levels of language prime was planned at the outset, separate ANOVAs were conducted for each level of language prime. The time course analyses for the Dutch language prime condition revealed a relatedness effect for only one single time window – that is, the 900–1000 ms epoch [$F(1,19) = 5.80$, $p < .05$]. The time-course analyses for the English language prime condition yielded a relatedness effect in the 600–700 ms epoch [$F(1,19) = 5.34$, $p < .05$] and the 900–1000 ms epoch [$F(1,19) = 16.65$, $p < .01$]. Thus, in contrast to the results of the overall ANOVA, the relatedness effects for each of the language prime conditions were much more restricted. The only window that yielded significant priming for both language prime conditions was the 900–1000 ms epoch. Note that Chwilla and Kolk (1998), using exactly the same presentation conditions in a monolingual lexical decision experiment, observed maximal N400 relatedness effects in this 900–1000 ms time-window. Therefore, we identified this window as the *N400 window*.

In the English language prime condition, no reliable ERP relatedness effects were observed in the 200 ms immediately preceding the N400 window (i.e., the 700–900 ms latency windows). This suggests that the early effect faded away before the 900–1000 ms window that we assume captures the N400 priming effect. Nevertheless, because in the critical English language prime condition an early relatedness effect was present, it could still be argued that the early effect may have contributed to or may have caused the later relatedness effect. We conducted the most conservative test that we could think of to test the hypothesis that the relatedness effect in the 900–1000 ms window was caused by an earlier effect. We aligned the waveforms immediately preceding the N400 window, using the 800–900 ms epoch as a baseline. If, indeed, the N400 effects were caused by the earlier effect, then the effect should disappear with the use of this baseline. The main result of these analyses was that clear semantic priming effects were still obtained both in the overall analysis [$F(1,19) = 14.86$, $p < .01$] and in the analysis for the English language prime condition [$F(1,19) = 17.67$, $p < .001$] and the one for the Dutch language prime condition [$F(1,19) = 4.83$, $p < .05$]. From this we conclude that the early effect does not underlie the N400 bilingual priming effect obtained in the present article.

Follow-up tests, aimed at a further examination of the scalp distribution of the bilingual N400 priming effect in contrast to the previous analyses, were based on the midline and the lateral analyses of the 900–1000 ms window using a pre-Item 3 baseline.[5] Main effects of electrode were obtained [$F(2,38) = 7.45$, $p < .01$ for the midline ANOVA and $F(4,76) = 4.87$, $p < .05$ for the lateral ANOVA]. Post hoc tests, however, did not reveal significant differences in N400 amplitude (collapsed across relatedness) neither for the midline nor for the lateral electrodes.

[5] The midline and the lateral analyses provide more relevant information about the anterior–posterior distribution and left–right hemispheric differences than the overall analysis in which all electrode sites are put into one single factor.

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Table 4. *Mean N400 amplitude within the 900–1000 ms latency range for different electrode positions as a function of Language Prime and Relatedness using a pre-Item 3 baseline*

	Fz	Cz	Pz	F7	F8	LAT	RAT	LT	RT	LTP	RTP	OL	OR
	English Language Prime												
Unrelated	−0.22	2.78	3.11	0.38	−0.79	0.41	−0.93	0.23	−0.66	0.58	−0.99	−0.72	−3.77
Related	1.97	5.10	5.24	1.08	0.67	1.14	0.71	1.89	1.60	2.42	1.11	0.90	−2.51
Difference	−2.19	−2.33	−2.13	−0.70	−1.45	−0.74	−1.64	−1.66	−2.26	−1.84	−2.10	−1.61	−1.26
	Dutch Language Prime												
Unrelated	0.19	3.15	3.76	0.83	−0.30	0.68	−0.70	0.61	−0.29	1.00	−0.30	−0.33	−2.94
Related	2.88	6.01	6.11	1.71	0.86	1.77	0.99	2.54	2.12	3.35	1.85	1.49	−1.64
Difference	−2.69	−2.87	−2.35	−0.89	−1.16	−1.09	−1.69	−1.93	−2.40	−2.35	−2.15	−1.83	−1.30

The N400 priming effect (Difference) was computed by subtracting the mean amplitude of the related condition from the mean amplitude of the unrelated condition.

The Relatedness by Electrode interaction was not significant for the midline electrodes [$F < 1$] but it was significant for the lateral electrodes [$F(4,76) = 4.55$, $p < .05$]. Post hoc Newman Keuls tests revealed that significant N400 effects were present at the temporal, temporoparietal and at occipital electrodes ($p < .05$), but not at frontal or anterior temporal sites. The separate analyses for the two levels of language prime did not reveal Relatedness by Electrode interactions [F*s* < 2.5]. As Table 4 shows for both the English and the Dutch language prime conditions, N400 priming effects of at least 1.5 μV were present at all electrodes, except from three anterior sites (i.e., F7, F8 and LAT) and the right occipital site (i.e., OR). The lateral ANOVA revealed a main effect of Hemisphere [$F(1,19) = 7.87$, $p < .05$], and a three-way interaction between Hemisphere, Relatedness, and Electrode [$F(4,76) = 4.39$, $p < .05$]. The main effect of Hemisphere reflected that overall amplitudes were more negative over the right than the left hemisphere (−0.30 and 1.10 μV). The interaction revealed that N400 priming effects at the following electrodes were somewhat larger over the right than the left hemisphere (see Table 4: F8 versus F7, RAT versus LAT, RT versus LT, RTP versus LTP). On the one hand, the N400 bilingual priming effects resembled the monolingual N400 priming effects, in that bilingual N400 priming effects (a) were largest over centro-parietal electrodes, and (b) tended to be larger over the right than the left hemisphere. On the other hand, the bilingual N400 priming effect appears to be more anteriorly distributed than the classical monolingual N400 priming effect. This more frontal distribution, however, could be caused by several factors such as differences in task (e.g., the requirement to judge the lexical status of three letter strings instead of one letter string) or presentation conditions, and is therefore not necessarily related to L2 processing. A more precise characterization of the scalp distribution of bilingual N400 priming effects awaits an experiment in which the topographies of bilingual and monolingual N400 priming effects are compared directly.

Taken together, the results of the ERP analyses show that interlingual homographs yielded clear N400 priming effects in the second language. N400 priming effects were present in both language prime conditions, indicating that the language of Item 1 (Dutch versus English) did not modulate the semantic priming effect from the interlingual homograph (Item 2) on the related target word (Item 3).

General discussion

Reaction times and event-related brain potentials were recorded while participants performed a generalized lexical decision task on triplets of items. The two main findings of the experiment were as follows. First, reliable RT and N400 semantic priming effects were obtained in the second language (English) of Dutch–English bilinguals. Target words that were semantically related to homographs presented as primes were reacted to faster and elicited smaller N400 amplitudes than words that were unrelated to the interlingual homograph primes.

Second, the RT and N400 semantic priming effects were not modulated by the immediate context. Regardless of the language of the prime preceding

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the interlingual homograph (English or Dutch), target words that were related to the English reading of the homographs were responded to faster and elicited smaller N400 amplitudes than unrelated target words. This result speaks against theoretical views that ascribe a strong influence to contextual factors, for instance views that assume that presentation of a Dutch word together with an interlingual homograph may induce complete suppression of its English reading (cf. Dijkstra, Timmermans and Schriefers, 2000).

The absence of a context effect is all the more remarkable because we set up the experiment so that it should yield maximal effects of language prime. We presented the language prime simultaneously with the interlingual homograph (prime on the left, interlingual homograph on the right, separated only by a plus sign), while the item semantically related to the homograph was presented only later. Furthermore, the language primes were always highly frequent words in English or Dutch, and our analysis of the effect of the position of nonwords in triplets clearly indicated that the two items being presented first on a trial were processed from left to right. Thus, despite maximizing the chances of suppression, reliable RT and N400 semantic priming was obtained. Apparently, even when the language prime was a Dutch word, the Dutch reading of the homograph was incapable of suppressing the semantics of its English reading.

In line with the view that the N400 priming effect reflects post-lexical integration processes, we interpret the N400 results as indicating that an English target word that is semantically related to a preceding interlingual homograph is more easily integrated than an unrelated target word. Furthermore, the independence of the N400 relatedness effect of the language of the prime (Dutch versus English word) strongly suggests that the amount of activation that the English reading of the homograph receives is not reduced by a simultaneously presented Dutch language prime. Otherwise, integration of a semantically related target word with the homograph should be more difficult in the presence of a Dutch language prime than in the presence of an English language prime. As a consequence, the N400 effect should be reduced in the presence of the Dutch relative to the English language primes. In other words, although the N400 priming effect itself is a measure of post-lexical integration processes, its independence of Language Prime condition suggests that the English reading of the homographs is activated in a bottom-up way unaffected by the preceding language prime.

Dijkstra et al. (1998) have argued that response patterns in RT paradigms reflect both bottom-up identification processes and strategy-dependent decision processes. In contrast, the observed N400 effects in the present semantic priming study may be less sensitive to relatively late decision and response selection processes. Recent results show that the occurrence of RT mediated priming is strongly affected by task, whereas for the N400 similar priming patterns were obtained across tasks (Chwilla et al., 2000). Thus, the present findings provide additional support for a bottom-up activation process of the English reading of interlingual homographs in native speakers of Dutch that is largely independent of an immediate language context containing a Dutch or an English word.

According to a language nonselective account, the following events happen on each trial. All three items in a triplet are recognized automatically and bottom-up, i.e. on the basis of their input characteristics (e.g., lexical orthographic structure and frequency). Even when the language prime is a Dutch word, both the Dutch and the English reading of the simultaneously presented homograph are maximally activated. In this view, our data indicate that the Dutch language primes immediately preceding the interlingual homographs did not affect the semantic activation of the English reading of the interlingual homographs. Of particular interest here are the ERP data, because they provide the first support for this view in terms of brain activity. Following this account, the strong local context effects found by Dijkstra, De Bruijn et al. (2000) in the second part of the English lexical decision task upon the introduction of exclusively Dutch items (see Introduction) should be ascribed to decision-level effects, dependent on the specific task demands in that study.

Of course, the assumption of language nonselective access that we make was not explicitly tested in our study, even though it is based on strong evidence from the available literature (see Introduction). Including conditions in the present experiment that would provide additional support for this assumption was unfortunately not feasible because of the restrictions the ERP technique imposes on the complexity of the experimental design.

Before turning to the general implications of the present study, there is one potential problem that we must address. The N400 effect in the Dutch language prime condition could be the result of an integration problem of the Dutch prime with the other words of the triplet, given that at least two of the three words (the Dutch language prime and the English target) belong to different languages. Note that this situation does not hold for the English prime condition in which all three words come from the same language. We can therefore test this alternative hypothesis by

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directly comparing the ERPs for the unrelated condition preceded by an English language prime to those for the unrelated condition preceded by a Dutch language prime. The ERPs in the two unrelated conditions matched each other quite closely. This was confirmed by an additional ANOVA with the factors Language Prime and Electrode for the N400 window (900–1000 ms) that showed no effect of Language Prime for the unrelated conditions ($F < 1$), nor for the related conditions [$F(1,19) = 1.28$, $p = .27$]. Thus, the observed N400 priming effect cannot be attributed to an integration problem of the Dutch language prime with the following two words having an English reading.

What are the consequences of the present study for models of bilingual word recognition? In the introduction we contrasted language nonselective access models that assume that lexical selection can be speeded under particular circumstances by suppressing lexical candidates from the nontarget language (Dijkstra et al., 1998; Green, 1998), with models assuming that only decision processes operating on the output of the identification system are context-sensitive (Dijkstra, De Bruijn et al., 2000). The present data provide support for the latter position. Therefore, they seem to be at deviance with the variant of the BIA model (Dijkstra and Van Heuven, 1998) that assumes that language nodes, preactivated on the basis of context items, are able to suppress lexical candidates from another language. However, they are compatible with a version of the BIA model assuming that lexical candidates activated within an identification system are proposed for selection to a decision mechanism incapable of adapting their activation levels. In line with this view, Dijkstra, Timmermans and Schriefers (2000) have proposed to consider the language nodes in the BIA model as language labels, representations within the identification system that represent the languages to which items belong. However, because suppression is a useful and pervasive mechanism in cognitive psychology in general (see Dijkstra and Van Heuven, 1998, for further discussion), and has recently been applied with success in language switching tasks (Green, 1998; Kroll, Dietz and Green, in preparation), we will need further confirmation before replacing the old version of the BIA model with a new one. Further studies will explore different variants of the lexical decision paradigm applied here to assess the generalizability and task sensitivity of the present findings.

In sum, our study has shown that combining RTs and ERPs provides a promising technique for research in the domain of bilingual word recognition. Because of their excellent temporal resolution, ERPs can provide important additional information that remains unseen when only RTs are measured. Further extensions of the present research immediately come to mind. Rather than introducing semantic relations in L2, Dutch translation equivalents of English words could be included in the triplets as primes. This might allow an examination of cross-language priming effects, perhaps not only from L2 into L1 (backward translation) but also from L1 to L2 (forward translation). Given that L2 is the bilingual's weaker language, it has been more difficult up to now to show effects from L2 on L1 in RT research. ERPs may provide a measure that is more sensitive in this respect.

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