Title

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Bilinguals activate words from both languages when listening to spoken sentences: Evidence from an ERP-study

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Abstract

The current study examines whether bilingual word recognition in spoken sentences is influenced by cross-lingual phonological similarity. ERPs were measured while German-English bilinguals listened to German sentences. Target words in the sentences were either German-English homophones (e.g., *eagle* – *Igel* ‘hedgehog’), German words that were phonologically closely related to English words (e.g., *kitten* – *Kittel* ‘smock’), or German words that had no phonological relation to English words (e.g., *Ziegel* ‘brick’). ERPs to target words showed an N400-like facilitation effect for words with cross-lingual phonological overlap (homophones and German-English related words) compared to words with no cross-lingual overlap. However, these results were restricted to bilinguals who learned both languages before age 6, but not for those bilinguals who learned English after age 6. This suggests that early bilinguals activate words from both languages when processing spoken sentences in their dominant language-context.

Keywords: Lexical access; Word recognition; Bilingualism; N400.

Introduction

A crucial question in bilingual research is whether lexical access in bilinguals is language-selective, i.e. whether recognition of words in one language of a bilingual involves activation of words from the bilingual’s other language. In the last years, a growing body of studies suggests that this is, indeed, the case. These studies provide evidence for models of bilingual word recognition which assume that lexical access is not always constrained by language context (e.g., the BIA+model; Dijkstra, Grainger & Van Heuven, 1999; Dijkstra & Van Heuven, 2002). Yet most of these studies investigated word recognition of isolated, visually presented words (for some recent studies see Wu & Thierry, 2010; Martin, Dering, Thomas & Thierry, 2009; Kerkhofs, Dijkstra, Chwilla & De Bruijn, 2006; De Bruijn, Dijkstra, Chwilla & Schriefers, 2001). Thus, the question arises in how far the results can be generalized to spoken word recognition and to word recognition in sentence context – the modality and context in which most communication occurs. Indeed, for monolinguals, there is evidence that lexical access in auditory and visual word recognition involves autonomous systems (e.g., Taft, 1986; Kouider & Dupoux, 2001) and that word recognition in single-word context dramatically differs from word recognition in sentence context (e.g. Van Petten, 1995).

Spivey and Marian (1999) report one of the few studies investigating spoken word recognition in bilinguals. They investigated whether Russian-English bilinguals’ word recognition in Russian is influenced by knowledge of English words. The participants saw familiar objects on the screen and were instructed to perform an action on one of the items. Crucially, the labels for the target image and distracter image overlapped phonologically across languages. For example, participants saw a stamp (*marku* in Russian) and a marker (*flomaster* in Russian) and received the Russian instruction *Ploji marku nije krestika* (‘Put the stamp below the cross’). Tracking the eye-movements of their participants, Spivey and Marian showed that Russian-English bilinguals considered the marker as a target before finally picking up the stamp. This suggests that participants briefly activated the English object-labels even though the experiment only involved Russian and it was therefore neither necessary nor required to activate English words. This result provides evidence that lexical access in bilinguals is not language selective in auditory word recognition. However, in this study, the L2 competitor (e.g., marker) was visually adjacent to the target. This is not the case in our everyday communication and might influence participants’ responding in a manner not typical to standard lexical access. In addition, the sentences in Spivey and Marian’s study were highly restricted (e.g., ‘Put the stamp below the cross’), whilst listeners are typically faced with the task of recognizing words in more variable sentence contexts.

A study investigating visual word recognition in sentence context was conducted by Duyck, van Assche, Drieghe and Hartsuiker (2007). They presented Dutch-English bilinguals with orthographically presented English sentences that contained a cross-language cognate like *cat* (Dutch *kat*). A first experiment presented the cognate as the final word in the sentence and measured subjects’ response times to judge the lexicality of the sentence-final word. A follow-up experiment presented the cognate in sentence-medial position and monitored subjects’ eye-movements while reading the sentences. The results indicate that subjects show lower lexical decision times for Dutch-English cognates and that subjects read Dutch-English cognates embedded in sentences faster compared to words with no cross-lingual overlap. This suggests that bilinguals activate words from both languages when reading sentences that are presented in their L2. Interestingly, this also seems to hold for L1 reading. Van Assche, Duyck, Hartsuiker and Diependale (2009) monitored the eye-movements of Dutch-English bilinguals while reading Dutch sentences that contained English-Dutch cognate words like *oven*. They replicate the effect obtained by Duyk et al. (2007): Reading times of cognate words were faster than those of control words. This is especially interesting because it suggests that not only do bilinguals activate native words when reading in L2, but they also activate L2 words when reading in L1. However, both studies only compared recognition of cognate words and words with no cross-lingual overlap. Thus, the effect might be bound to only those words that exist in both languages of the bilingual.

Global language context might also influence word recognition in bilinguals. Elston-Güttler, Gunter and Kotz (2005) presented advanced German learners of English with a movie narrated in either English or German. They then measured ERPs to orthographically presented English sentences that ended in a German-English homograph. Additionally, they measured subjects' response times to judge the lexicality of a word semantically related to the homograph. In the first block (36 trials) of the testing phase, ERPs and behavioural data differed for homographs, but only for those subjects who saw the German movie before. Neither behavioural nor ERP data showed a priming effect in the rest of the testing phase. It thus seems that the local English sentence context prevented the activation of the German interpretation of the homograph and that the global language context provided by the movie had small and short-lived effects on lexical activation.

Taken together, results are mixed concerning bilingual word recognition in sentence context. While Duyck and colleagues show an effect of cross-lingual relation on word recognition, Elston-Güttler and colleagues only find very limited evidence of cross-language activation. Yet, it seems vital for our understanding of bilingual word recognition to see how bilinguals cope with cross-lingual relations in sentences, and especially in spoken sentences. The current study broadens the scope of the preceding studies in several ways. First, we explore whether bilinguals activate words from both languages when listening to spoken sentences instead of reading in one of their languages. Second, we used both cross-lingual homophones *and* words that were phonologically closely related across languages, to see how far the effects of earlier studies are restricted to cognate words. Third, we tested early and late bilinguals to see how age of acquisition affects lexical processing in bilinguals. And fourth, the task presented to subjects during the experiment was non-linguistic. This ensured that we did not draw subjects' attention to the target word or explicitly engage processes related to lexical access. More precisely, we presented German-English bilinguals with spoken German sentences while we measured their ERPs. At the end of each sentence, subjects were presented with either a triangle or a rectangle and asked to decide the shape of the visually presented form. Subjects were told that the main purpose of the task was the visual form and that the sentences were intended to distract them. Crucially, the target word in the sentences was an English-German homophone (homophone condition), or a German word that forms a minimal pair with an English word (related condition), or a German word that has no cross-lingual relation to English words (unrelated condition). If bilinguals indeed activate words from both languages when recognizing words in fluent speech, we expect differences in lexical activation for the words with cross-lingual relation compared to the unrelated condition. Second, if the effects that have been found in earlier studies are not restricted to cognate words and homographs, we expect to find an effect of cross-lingual activation for homophones and related words as well. Third, if age of acquisition does not influence lexical activation in bilinguals, we expect no differences between our two groups of participants (highly proficient bilinguals who learned both English and German before age 6, or L2 learners who learned English after age 6).

Material and Methods

Participants

A total number of 18 German-English bilinguals participated in the study (7 female). Participants' mean age was 33.5 years, ranging from 18 to 65 years. All participants lived in Germany when the study was conducted. 10 out of 18 participants learned both English and German before age 6 (early bilinguals), the remaining 8 participants learned English after age 6 (late bilinguals). Participants rated their fluency in reading, writing, listening, speaking and grammar on a scale from 1 (very low) to 10 (very high) (questionnaire adapted from Rüschemeyer, Nojack & Limbach 2008). Mean fluency was rated 9.3 for German (range 7.6 to 10) with 9.3 for early bilinguals (range 7.6 to 10) and 9.2 for late bilinguals (range 7.6 to 10). Mean fluency for English was rated 8.9 (range 6 to 10) with 8.6 for early bilinguals (range 6 to 10) and 9.3 for late bilinguals (range 7.6 to 10). Participants also rated how often they use English and German in everyday life (with family, friends and colleagues, when reading books, listening to the radio and watching TV). Mean usage of German was 60.4%, with 60.8 for early bilinguals and 60 for late bilinguals; mean usage of English 40%, with 39.2% for early bilinguals and 39.6% for late bilinguals. T-tests comparing language fluency and language use between participants that learned English before and after age 6 did not show any significant differences. All participants had normal or corrected-to-normal vision and self-reported normal hearing. They signed informed consent to take part in the study and received 15 Euros for their participation.

Stimuli

The audio stimuli consisted of 180 German sentences spoken by a female native speaker of German in a neutral tone of voice. Stimuli were recorded in a quiet room, using a sampling rate of 44100 Hz. Stimuli were volume matched. All sentences were main clauses with no subordinate clauses so that the sentences began with the subject, followed by the verb, a direct object and in some cases an indirect object. The 180 sentences were split into 6 blocks, each containing 30 sentences. Across blocks the sentences were repeated and held constant as far as possible, although sometimes slight adjustments had to be made in order to prevent grammatical or semantic anomalies. The target word was always the subject of the clause, i.e. occurred preverbal, so that participants could not build expectations about the referent (see e.g. Altmann & Kamide, 1999, for the influence of verb information on referent selection). Sentences were not semantically restricted so that upcoming words could not be anticipated based on sentence context. At the same time sentences were not semantically incongruous or inappropriate (see e.g., Schwartz & Kroll, 2006, for the influence of sentence context on bilingual word recognition). In half of the sentences target words were German words. In the other 90 sentences, target words were German pseudowords. Words could be either cross-lingual homophones, like *Igel* 'hedgehog' and *eagle*, German words that are phonologically closely related to English words, like *Kittel* 'smock' and *kitten*, or German words that have no relation to English. Frequency of the words and neighborhood size was matched across conditions (average number of neighbors: homophones =4.8, related words =4.5, unrelated words =4.5; average frequency class in Wortschatz (Quasthoff, Richter & Biemann, 2006): homophones =12, related words =12, unrelated words =13). Target words were also matched in length with respect to number of phonemes and duration across conditions (average number of phonemes: homophones =3.4, related words =3.4, unrelated words =3.5; average duration: homophones =593 ms, related words =529 ms, unrelated words =576 ms). Each type of word (homophone, related, unrelated) appeared in 30 sentences each.

Visual stimuli were created in an image editing program and then exported as pictures. The stimuli were either a filled red triangular shape or a filled red rectangular shape. Each shape measured 300 x 300 pixels, and was displayed against a black background

Procedure

Participants were seated in a dimly lit, quiet experimental room, facing a 92 cm wide and 50 cm high TV screen at a distance of 100 cm. All conversation during preparation for the experiment, as well as the instruction sheet, was in German. Participants were told that we were interested in how visual perception is affected by background noise. They were instructed that they will hear sentences while two kinds of objects, triangles and rectangles, appear on the screen. Their task was to ignore the sentences and to indicate as fast as possible which object they had seen by pressing the corresponding button on an X-Box controller. Participants were presented with 180 trials in random order.

Each trial started with a white fixation cross on a black background presented in the middle of the screen. Auditory presentation of the sentence stimuli was timed so that the target word started 1000 ms into the trial. At the end of the sentence, an object (a triangle or rectangle) appeared on the screen. The trial ended automatically when the subject had given a response. The visually presented form was a triangle in one-third of the trials, and a rectangle in the remaining two-thirds of the experiment. The ratio of triangles to rectangles attempted to ensure that subjects would stay focused on the decision task.

ERP recording

Electrophysiological data was recorded using the Biosemi Active Two Amplifier system at a sampling rate of 2048 Hz from 32 Ag/AgCl electrodes placed according to the 10-20 convention. Electrode offsets were kept < 25 µV. Electroencephalogramm was re-referenced offline to the averaged mastoid reference. EEG data was then filtered off-line using a 0.01 Hz high-pass forward filter and a 25 Hz low-pass, zero-phase shift filter. Blink and movement artifacts were automatically rejected using an 80 Hz amplitude cut-off on the mastoid and three eye channels (left, right and lower eye). Epochs were defined from -200 to 1000 ms after the onset of the target word. Baseline correction was performed in reference to pre-stimulus activity (-200 to 0 ms).

Data analysis

Data was averaged across all trials, split by participant, electrode and condition. We then calculated mean amplitudes for 50 ms segments, ranging from 200 ms before the target word onset to 1000 ms after the target word onset, split by participant, condition and electrode. This allowed us to detect periods of significant differences across conditions. Statistical analysis was performed on mean measures of frontal, central, parietal and occipital sites in both hemispheres [right frontal (FC2, FC6), left frontal (FC1, FC5), right central (C4, CP2, CP6), left central (C3, CP1, CP5), right parietal (P4, P8, PO4), left parietal (P3, P7, PO3), right occipital (O2) and left occipital (O1)] in an N400 latency window (500 to 1000 ms). Note that the latency window is slightly shifted because N400 effects tend to appear later in bilinguals compared to monolinguals, especially when they process their L2 (for a review see Moreno, Rodriguez-Fornells & Laine, 2008). Within-subject factors for repeated ANOVAS included condition (homophone/ related/ unrelated), hemisphere (left/ right) and site (frontal/ central/ parietal/ occipital), while age of acquisition (before/after age 6) served as a between subject factor. The Geisser-Greenhouse correction was always applied.

Results and Discussion

Figure 1 plots the brain activity in the homophone, related and unrelated condition for early bilinguals. The pattern illustrated in Figure 1 indicates that ERPs to homophone and related condition were less negative compared to the unrelated condition between 500 to 1000 ms. Figure 2 plots this difference by comparing the averaged mean amplitudes per condition for early bilinguals. Figure 3 plots that the averaged mean amplitudes for late bilinguals are not different between conditions.

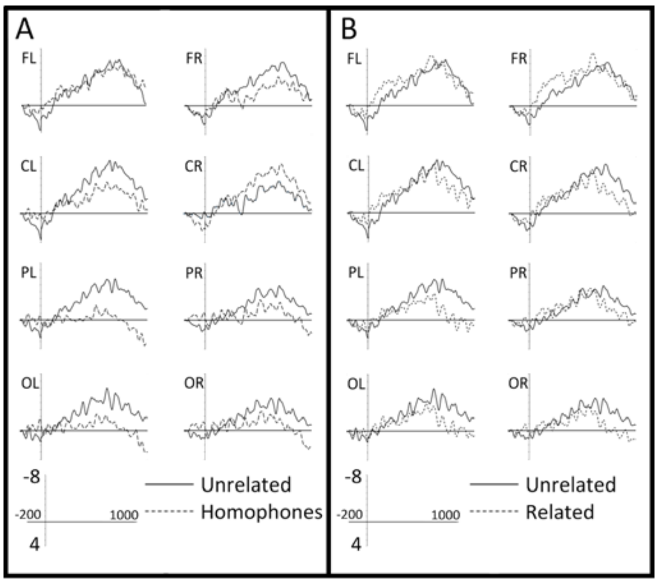

Figure 1: ERPs elicited by critical targets at selected electrode sites in early German-English bilinguals. Waveforms in panel A show the average for cross-lingual homophones (dashed line) and unrelated words (solid line). Waveforms in panel B show the average for words that are phonologically related to English words (dotted line) and unrelated words (solid line).

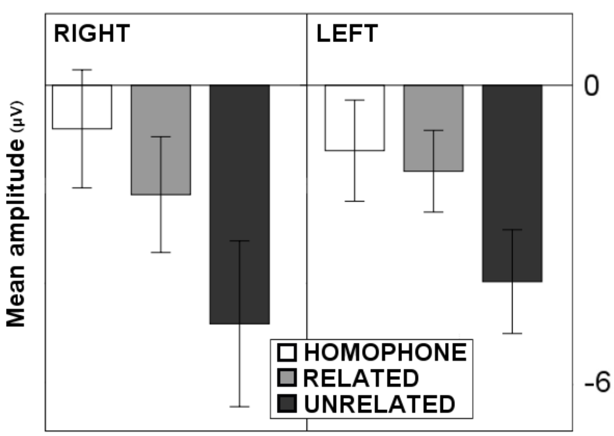

Figure 2: Mean amplitude in the 500 to 1000 ms window for right and left hemisphere of early German-English bilinguals. Plots show the average for German words that are cross-lingual homophones (homophones), German words that are phonologically related to English words (related), and German words with no phonological relation to English words (unrelated).

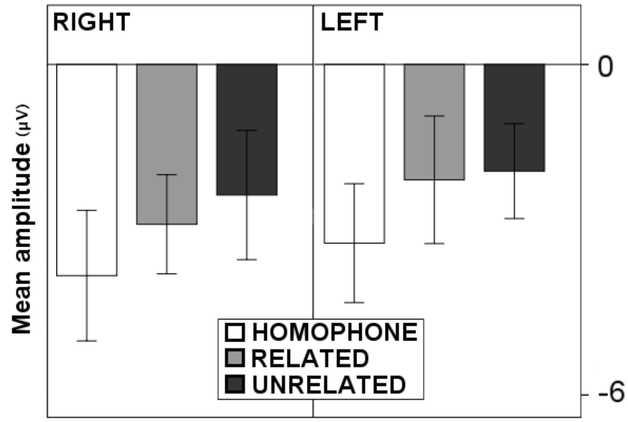

Figure 3: Mean amplitudes in the 500 to 1000 ms window for right and left hemisphere of late German-English bilinguals. Plots show the average for German words that cross-lingual homophones (homophones), German words that are phonologically related to English words (related), and German words with no phonological relation to English words (unrelated).

Statistical analysis confirmed this pattern of results. A repeated measures ANOVA showed a main effect of hemisphere ($F(1) = 5.436$, $p = .033$) and interactions of condition*age of acquisition ($F(1.95) = 4.717$, $p = .017$) and condition*site ($F(3.35) = 14.363$, $p = .073$). No other main effects or interactions approached significance. For further analysis, we split the data by age of acquisition and separately analyzed subjects who acquired both languages before age 6 (early bilinguals), and subjects who learned the second language after age 6 (late bilinguals). For the early bilinguals, planned comparisons showed a significant difference between the homophone and unrelated condition on left occipital (OL), right occipital (OR), left parietal (PL), and left central (CL) electrode sites ($t_{OL}(9) = 2.387$, $p = .041$; $t_{OR}(9) = 2.554$, $p = .031$; $t_{PL}(9) = 2.009$, $p = .075$; $t_{CL}(9) = 3.116$, $p = .012$). Similarly, there was a significant difference between related and unrelated condition on left occipital (OL), right occipital (OR), left central (CL) and right parietal (PR) electrode sites ($t_{OL}(9) = 2.603$, $p = .029$; $t_{OR}(9) = 3.261$, $p = .010$; $t_{CL}(9) = 2.941$, $p = .016$; $t_{PR}(9) = 2.388$, $p = .041$). There were no significant differences between homophone and related condition. For the late bilinguals, planned comparisons showed a significant difference between homophone and related condition on left frontal (FL), right frontal (FR) and right central (CR) electrode sites ($t_{FL}(9) = -4.584$, $p = .003$; $t_{FR}(9) = -2.258$, $p = .059$; $t_{CR}(9) = -2.194$, $p = .064$). There were no significant differences between related and unrelated condition, and a near-significant difference between homophone and related condition on left frontal electrode sites ($t(9) = -2.186$, $p = .065$).

In sum, the data show different effects depending on age of acquisition of the subjects. Early German-English bilinguals, who learned both languages before age 6, show a more positive N400-like effect for homophones and related words compared to unrelated words. This indicates a facilitation effect for the recognition of German words that are phonologically related to English words or cross-lingual homophones. Interestingly, we found no further difference between homophones and related words indicating that homophones do not lead to different activation compared to words that are minimal pairs across languages. In sharp contrast, German-English bilinguals of similar proficiency, who learned English after age 6, do not show differences in the N400 effect for words that have a cross-lingual relation and control words. This suggests that late bilinguals do not automatically activate words from both their languages when recognizing words in fluent speech but that the effect is bound to those bilinguals who learned both languages very early in life.The finding that early bilinguals show a facilitation effect whilst recognizing words that have a cross-lingual relation fits nicely with earlier results on word recognition in bilinguals. It suggests that bilinguals activate words from both their languages when processing spoken sentences and not only when recognizing isolated words (e.g. Wu & Thierry, 2010; De Bruijn et al., 2001) or words in written sentences (e.g. Duyck et al., 2007, Van Assche et al., 2009). This finding is not trivial, since bilinguals might use different strategies in spoken and written language comprehension. Indeed, most day-to-day communication involves language in the spoken modality and in sentence context.

We also find a clear effect of age of acquisition on subjects' ERPs. While early bilinguals who learned both languages before age 6 show a facilitation effect for the recognition of cross-lingual related words, bilinguals who learned English after age 6 did not show such an effect. This difference is unexpected given that both groups of bilinguals were similarly high proficient speakers of English and German, and used English equally often in their daily life (as indicated by participants' self-rating in the administered questionnaire). For such highly proficient bilinguals, earlier results clearly indicate a cross-language priming effect (e.g., Kotz, 2001; Martin et al., 2009). Yet, most studies investigating lexical access in bilinguals used designs in which it is more likely that both languages would be triggered by explicitly presenting subjects with stimuli from both languages (see e.g., Martin et al., 2009; De Bruijn et al., 2001). Furthermore, as pointed out before, auditory and visual word recognition involve different systems and word recognition of isolated words is different from word recognition in sentence context. Thus, late bilinguals might not continuously activate words from both languages when they listen to sentences that are clearly uttered by a L1 native speaker in an obviously L1 language context where it is unlikely that an L2 word will be uttered. Nevertheless, Van Assche et al. (2009) find faster reading times for cognate words not only for L2 but also for L1 sentences. We suggest that the different findings originate from differences in the stimuli used. The most important difference between our study and theirs is that Van Assche and colleagues used cognate words while we used homophones and German-English minimal pairs. Cognates might be much more likely to elicit activation of the L2 compared to cross-language minimal pairs or homophones, given the overlap at both semantic and phonological levels in cognates. We further speculate that the difference between the bilingual groups arises because the two languages of the early bilinguals are more integrated or interconnected than the languages of the late bilinguals. However, this speculation requires further empirical substantiation.

What implications do our data have for models of bilingual word recognition? The finding that early bilinguals show a facilitation effects in recognizing words that have a cross-lingual relation, i.e. German-English homophones and minimal pairs, provides evidence for language non-selective lexical access, as predicted by models like the BIA+ model (Dijkstra, et al., 1999; Dijkstra & Van Heuven, 2002). The model assumes an integrated lexicon for both languages of a bilingual. Lexical access is, therefore, initially not language selective; rather, word candidates from both languages are accessed in parallel. The word identification system is assumed to be not affected by local or global language context, i.e. sentence context or surrounding language context. This assumption is in accordance with our finding that early bilinguals show a facilitation effect for cross-lingual related words despite the fact that neither the sentences in which the words are embedded nor the global language context provide any hint of a cross-language relation of the embedded words. However, the finding that late bilinguals do not show similar facilitation effects for words with cross-lingual relation in sentence context seems to contradict this prediction. Yet, although lexical access is initially not language selective, the model predicts that differences in activation of L1 and L2 words might occur because of differences in usage frequency and/or task related strategies. Despite the fact that we matched proficiency and language use of the bilinguals tested, the late bilinguals might use the English words corresponding to our German target words less frequently than the early bilinguals. According to the model, this would result in different resting-level activation of the L2 words and might, therefore, lead to differences in activation of the L2 words in the two bilingual groups. But it might also be that late bilinguals do not automatically activate words from both languages when recognizing words in fluent speech. The fact that they learned their second language later in life might lead to less integration and/or interconnection between lexical representations from both languages as assumed by models like the Revised Hierarchical Model of bilingual language processing (Kroll & Stewart, 1994). The model assumes two separate lexicons for the two languages of a bilingual. The lexical word form representations are assumed to be stored separately, while both languages share a common conceptual level. Although there exist connections both from L1 to L2 and from L2 to L1, the strength of the connections is mediated by proficiency. In principle, the assumption of two separate lexicons allows for language selective lexical access. Thus, the model would not necessarily predict co-activation of words from both languages in an obvious L1 context for late bilinguals.

Taken together, our results suggest that early and late bilinguals show differences in cross-language activation during word recognition. Our findings indicate that early bilinguals activate words from both languages when listening to fluent speech in one of their languages suggesting strong interconnections of the two languages. This complements earlier findings in two important ways: First, it shows that the earlier results of language-unconstrained lexical access for word recognition in orthographically presented sentences also applies to spoken word recognition in sentence context. Second, it shows that the earlier results obtained with cognates extends also to homophones with no meaning overlap and to cross-language minimal pairs. Crucially, such cross-language activation persists despite our task not drawing special attention to the target items and not requiring subjects to perform a language-based task. Concerning late bilinguals, our data suggest that global and/or local language context can eliminate the effect of cross-language relations. This might be due to differences in frequency of L1 and L2 words, task demands, or less strong interconnections of L1 and L2 words in late bilinguals.

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