Bilingual language control: An event-related brain potential study

Christoffels, I.K.; Firk, C.; Schiller, N.O.

BRAIN RESEARCH 1147 (2007) 192–208

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

Bilingual language control: An event-related brain potential study

Ingrid K. Christoffels[a,b,*], *Christine Firk*[b], *Niels O. Schiller*[a,b]

[a]*Leiden Institute for Brain and Cognition (LIBC), Leiden University, The Netherlands*
[b]*Department of Cognitive Neuroscience, Faculty of Psychology, Maastricht University, The Netherlands*

ARTICLE INFO

Article history:
Accepted 29 January 2007
Available online 9 February 2007

Keywords:
Bilingualism
Language switching
Cognate status
Inhibitory control
Language context
ERP
N2

ABSTRACT

This study addressed how bilingual speakers switch between their first and second language when speaking. Event-related brain potentials (ERPs) and naming latencies were measured while unbalanced German (L1)–Dutch (L2) speakers performed a picture-naming task. Participants named pictures either in their L1 or in their L2 (blocked language conditions), or participants switched between their first and second language unpredictably (mixed language condition). Furthermore, form similarity between translation equivalents (cognate status) was manipulated. A cognate facilitation effect was found for L1 and L2 indicating phonological activation of the non-response language in blocked and mixed language conditions. The ERP data also revealed small but reliable effects of cognate status. Language switching resulted in equal switching costs for both languages and was associated with a modulation in the ERP waveforms (time windows 275–375 ms and 375–475 ms). Mixed language context affected especially the L1, both in ERPs and in latencies, which became slower in L1 than L2. It is suggested that sustained and transient components of language control should be distinguished. Results are discussed in relation to current theories of bilingual language processing.

1. Introduction

Bilingual speakers show remarkable flexibility in their ability to control their language output. They can restrict their speech to one language only but also intentionally switch between languages in bilingual settings. The question arises how bilinguals select the intended language and what mechanisms they rely on when switching from one language to the other. Bilinguals vary in proficiency of their second language ranging from very high levels of proficiency (highly proficient bilinguals or balanced bilinguals) to low levels of proficiency (L2 learners and L2 attriters). Even highly proficient bilinguals usually have a dominant and a non-dominant language which is reflected, for instance, in faster picture-naming latencies for their first compared to their second language (e.g., Chen and Leung, 1989; Christoffels et al., 2006; Potter et al., 1984). However, under language switching conditions, this difference in naming latencies between L1 and L2 may disappear or even reverse, with shorter picture-naming latencies for the second than the first language (Costa and Santesteban, 2004; Costa et al., 2006; Meuter and Allport, 1999; Philipp et al., 2006; see also Kroll et al., 2006). Switching between languages may therefore profoundly affect production in the native tongue. In this study, we address intentional language switching and the impact of the bilingual switching context on distinguishing transient and sustained components of language control.

* *Corresponding author*. Cognitive Psychology Unit, Department of Psychology, Faculty of Social Sciences, Leiden University, P.O. Box 9555, 2300 RB Leiden, The Netherlands. Fax: +31 71 5273783.
E-mail address: ichristoffels@fsw.leidenuniv.nl (I.K. Christoffels).

0006-8993/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.brainres.2007.01.137

1.1. Lexical access and selection in bilingual language production

Lexical access in language production is usually assumed to occur in at least two stages: lexical selection and phonological encoding (e.g., Levelt et al., 1999). Given the semantically or conceptually driven activation of lexical items (so called *lemmas*, which specify the syntactic properties of words), lexical selection refers to the process of selecting a lexical item from the mental lexicon. In bilingual speech production, most evidence suggests that items of different languages are activated in parallel. That is, activation of lexical items is assumed to be language non-specific (e.g., Colomé, 2001; Costa et al., 2000; Hermans et al., 1998). However, it is less clear whether or not the corresponding phonological forms are also activated in both languages. To address this issue, Hermans et al. (1998) studied interference from the dominant language (Dutch) during naming in the non-dominant language (English) with a variant of the picture–word interference paradigm. Hermans et al. concluded that bilingual speakers cannot avoid interference from the non-target language during lexical selection but found no clear evidence for interference during phonological encoding.

More recent studies, using different paradigms, reached the opposite conclusion (Costa et al., 2000; Colomé, 2001; Rodriguez-Fornells et al., 2005; Roelofs, 2003). For example, Costa et al. (2000) concluded that the non-response language's phonology was activated in highly proficient Spanish-Catalan bilinguals based on a cognate manipulation. Cognates are words with similar phonological forms in two languages. For example, there is some form similarity between the German word *Brille* ('glasses') and the corresponding Dutch word *bril*, but not between the German word *Hose* ('pants') and the corresponding Dutch word *broek*. The cognate facilitation effect, i.e., faster responses to cognates than to non-cognates, can be accounted for if activation of the lexical items in both languages leads to the activation of the corresponding phonological segments. Pictures with cognate names may be named faster than pictures with non-cognate names because phonological forms of cognates may receive activation from both languages, whereas non-cognates only receive activation from the target language. Cognate facilitation can be found for speakers with different proficiency levels, not only in the L2 but even for a dominant L1 (Christoffels et al., 2003, 2006).

Rodriguez-Fornells et al. (2005) studied phonological interference from the non-target language when tacitly naming a picture in the target language. They used a go/no-go task where a response was required to one class of stimuli (*go*) and the response was to be withheld to another class of stimuli (*no-go*). German–Spanish bilinguals were asked to decide whether a picture name started with a vowel or a consonant in German. For example, they responded when the word started with a consonant (*go*) and withheld their response for words starting with a vowel (*no-go*). The stimuli were selected such that for half of the translation equivalents the German and Spanish words started both with a vowel or consonant, requiring the same response (congruent), or started differently (incongruent). There should be detectable effects of response conflict if the phonological representation of the non-target language name was activated. This interference was evident in reaction times (RTs) by a slower response for incongruent than congruent trials for bilinguals. In the event-related potentials (ERPs), an enhanced negativity with a frontal maximum was found between 300 and 600 ms for incongruent as compared to congruent trials. The functional magnetic resonance imaging (fMRI) data revealed effects in the left pre-frontal cortex and the supplementary motor area. According to Rodriguez-Fornells et al., the non-target language phonology was partly activated and executive control processing was recruited to cope with interference.

Note that the results from Hermans et al. (1998) may be reconciled with the later body of research. These authors argued that within an interactive rather than a discrete two-stage model of lexical access (in which phonological encoding only starts after one lexical item has been selected) their results may be interpreted as evidence in favor of activated phonological forms during the initial stages of naming.

Current evidence suggests that the non-target language is activated up to the phonological level. One important question is then how bilinguals prevent intrusions from the non-target language during speaking. Proposals about this hotly debated issue can be divided into whether lexical *selection* is language-specific or fundamentally language non-specific. Both views share the assumption that lexical items are somehow specified or tagged for language. According to a *language-specific selection* mechanism, only target language lexical items are considered for selection, irrespective of the activation level of non-target items. Lexical items belonging to the non-target language are simply not taken into account (e.g., Costa, 2005; Roelofs, 1998). Roelofs (1998) proposed that lexical access is conceptually driven and that production rules are marked for language thereby allowing only lexical items of the proper language to be selected irrespective of their level of activation. In contrast, language *non-specific selection* mechanisms assume that in principle items from both languages are considered for selection. Control over language of production is exerted by inhibition of non-target candidates such that target language candidates are most active and will therefore become selected (e.g., Green, 1998; Paradis, 1997).

A very influential model assuming non-specific selection is the Inhibitory Control (IC) model proposed by Green (1998). In the IC model, so-called *language task schemas* that are external to the bilingual lexico-semantic system compete to control the output from the bilingual lexico-semantic system. In order to speak in one language, all active lemmas whose language tags do not correspond to the target language are inhibited. When speaking in the weaker language (L2), the L2 task schema must suppress the task schema of the dominant language (L1) and inhibit L1 lemmas in the bilingual lexico-semantic system.

1.2. Language switching and inhibitory control

Language control in bilingual language production can be studied in a so-called language switching paradigm. In this paradigm, bilingual speakers are asked to name digits or pictures in their first or second language depending on, for example, a color cue. This results in language switch (switching from L2 to L1 or from L1 to L2) and non-switch trials. *Switching costs* are defined as the difference in naming latencies between switch and non-switch trials. According to

Green (1998), when switching between L1 and L2, the currently active schema has to be suppressed and the previously inhibited schema must be reactivated. This leads to costs when switching from one language to another. Moreover, the cost of switching is postulated to be asymmetric. It is harder to switch from the weaker L2 to the stronger L1 than vice versa because L1 is more strongly inhibited and requires more time to be reactivated. Why is L1 more strongly suppressed than L2? Green (1998) assumed that the language that is normally more active (L1) must be stronger suppressed in order to speak in the weaker language (L2).

Support for this assumption of reactive inhibition in the IC model comes from a language switching study by Meuter and Allport (1999). They tested the *task set inertia hypothesis* (Allport et al., 1994) which states that to enable the task set for the weaker task, the competing stronger task must be actively suppressed. On a switch trial from the weaker to the stronger task, the inhibition of the stronger task set must be overcome before the task can be performed. Meuter and Allport (1999) extrapolated these findings to language switching and indeed obtained asymmetrical switching costs, with higher costs for L1 than L2.

Jackson et al. (2001) also report findings that suggest that L1 is actively inhibited to access L2. They recorded ERPs during (predictable) language switching. The behavioral data revealed higher switching costs for L1 than L2. Further, they obtained a small increased frontal negativity for switch trials compared to non-switch trials around 310 ms which was significant when switching from L1 to L2 but not when switching from L2 to L1. The negativity was interpreted as an N2 component. An N2 is usually elicited by no-go responses compared to go-responses in go/no-go tasks. The N2 can be observed as a negative shift over fronto-central sites with a peak between 250 and 350 ms after stimulus onset. This effect has been related to response inhibition (e.g., Jodo and Kayama, 1992; Pfefferbaum et al., 1985; Thorpe et al., 1996) and more recently to response conflict monitoring (e.g., Nieuwenhuis et al., 2003; Donkers and Van Boxtel, 2004). According to Jackson et al. (2001), the switch-related modulation of this frontal negativity suggested that L1 is more inhibited when accessing L2 than vice versa, and frontal brain regions may be involved in language switching.

The frontal cortex is related to general executive functions such as response switching and response suppression (e.g., Dove et al., 2000; Konishi et al., 2003; Sohn et al., 2000). Switching between languages may thus involve increased general executive processing. This view is supported by neuroimaging studies that yielded enhanced activation of the dorsolateral pre-frontal cortex during language switching (Hernandez et al., 2000, 2001). Hernandez et al. (2000, 2001) suggested that the dorsolateral pre-frontal cortex serves to attenuate interference that results from actively enhancing and suppressing two languages in alternation.

Language control, or the lack of it, can have important consequences for bilinguals. For example, Fabbro et al. (2000) described a bilingual patient (FK) who could not control switching between Friulian and Italian after a lesion to the frontal cortex including the anterior cingulate. Although no aphasic symptoms were observed in either language, FK produced at least 40% of his utterances in the inappropriate language. Another bilingual Urdu-English frontal lobe patient was tested using a language switching paradigm (Meuter et al., 2002). When required to switch from the dominant to the non-dominant language, the patient made a high number of erroneous dominant language responses. Meuter et al. (2002) suggested that the patient's frontal lobe damage resulted in an inability to inhibit his dominant language. The lack of aphasic symptoms of these patients supports the assumption that switching between languages is independent of the linguistic system and that language control is supported by a general executive control mechanism that involves the frontal cortex.

However, the question remains whether or not this control mechanism involves *reactive inhibition* of the non-target language, as suggested by the IC model. Reactive inhibition means that inhibition is only exerted after lexical items of the non-target language have been activated from the conceptual-semantic system (Green, 1998). Recently, Costa and Santesteban (2004) suggested that only low-proficient bilinguals rely on inhibitory control, whereas highly proficient bilinguals rely on a language-specific selection mechanism during lexical selection. Using a language switching paradigm they found that highly proficient Catalan–Spanish bilinguals do not show asymmetrical switching costs when switching between their first and second language. This fits with an inhibitory control account since small differences in language proficiency should be accompanied by small differences in the level of inhibition applied to the two languages. However, for these proficient participants switching costs were also symmetric for switching between the first and a less proficient third language. Costa and Santesteban (2004) suggested that when bilinguals have developed a language-specific selection mechanism, it will be applied to any language regardless of the proficiency level of that language. Recently, Costa et al. (2006), used the same paradigm on proficient bilinguals. In support of their suggestion, testing these participants on their L2 and L3 again yielded symmetric switching cost. However, the costs were asymmetric for these participants when switching between L3 and L4 and between L1 and a recently learned language. Clearly, if high proficient bilinguals indeed develop a language-specific selection mechanism, there are limits to the situations it can be applied.

1.3. Experimental outline

The main goal of the present study was to investigate language control and phonological activation of the non-response language in different language settings using behavioral measures and ERP recordings. We tested phonological activation of the non-target language and (inhibitory) control elicited by language switching in one paradigm using overt speech.

Unbalanced German–Dutch bilingual speakers who frequently switch between their two languages in daily life performed a picture-naming task. Participants switched between their first and second language in a mixed language block and performed whole blocks in a single language (L1 or L2). During all blocks, the response language was cued by the color (red or green) of the picture. On non-switch trials, participants responded in the same language as on the preceding trial, and on switch trials, the response language

Table 1 – Mean reaction times in ms and standard deviation in brackets for blocked and mixed conditions, and mixing cost (blocked minus non-switch) and switching costs (switch minus non-switch)

	L1			L2		
	Cognates	Non-cognates	Mean	Cognates	Non-cognates	Mean
Type of trial						
Blocked	710 (92)	735 (80)	722	773 (119)	854 (134)	813
Non-switch	809 (83)	902 (93)	856	780 (70)	846 (88)	813
Switch	860 (89)	935 (89)	897	847 (80)	887 (95)	867
Type of cost						
Switch cost	51	33	41	67	41	54
Mixing cost	99	167	134	7	−8	0

changed from the preceding trial to the current trial. Picture names were either cognates or non-cognates.

In the blocked language condition, it was predicted that reaction times would be faster in L1 than L2 since participants were unbalanced bilinguals. A cognate facilitation effect was predicted with faster naming latencies for pictures with cognate names than non-cognate names. This effect was expected to be asymmetric, i.e., larger for L2 than L1 in the blocked conditions. In the mixed language context, we expected asymmetrical switching costs, as our participants were not highly proficient. Predictions about the behavior of the cognate facilitation effect in the mixed language context are more difficult to make. On the one hand, the mixed language context might cause both languages to be relatively active, which may increase the cognate facilitation effect. On the other hand, if the locus of inhibitory control is at the lexical level (Green, 1998), then phonological activation of the non-target language should be prevented and no facilitation should be observed.

As for the ERPs, because language tends to strongly impact reaction times and to interact with other variables, we expected language to differentially affect the ERP waveform in all conditions. Based on Jackson et al. (2001), we expected that language control modulates the amplitude of an N2-like component in the ERP waveforms with higher amplitudes for switch than for non-switch trials. Moreover, we explored the possible effect of cognate status on ERPs, which may serve as a marker of phonological processing in overt speech production. Also, form overlap between translation equivalents may influence the amount of conflict between languages and therefore modulate the ERPs.

Crucially, the current study allows us not only to investigate switch costs, but also the so-called mixing cost. Non-switch trials can be directly compared to trials from blocked language conditions (mixing cost). This may help to advance our understanding of the effect of a mixed language context on bilingual word production. Naming latencies in mixed conditions often reverse compared to blocked conditions. With our design, we are able to compare sustained language control as evidenced by context effects and transient trial-by-trial intentional control induced by switching between languages. In other words, we may distinguish between sustained and transient components of language control. General cognitive control research suggests that these components are functionally dissociable (Braver et al., 2003). This distinction may be particularly useful for bilingual language production.

2. Results

2.1. Behavioral data

To investigate the effect of language context, comparisons were made between non-switch trials from blocked and mixed language conditions. The effect of language switching on naming latencies was explored by comparing non-switch trials to switch trials from mixed blocks. Mean reaction times, switch and mixing costs are presented in Table 1.

2.1.1. Blocked language condition

Analyses of variance (ANOVAs) with language (L1 vs. L2) and cognate status (cognates vs. non-cognates) revealed main effects of language as well as cognate status ($F(1, 19)=16.58$, $p<0.01$ and $F(1, 19)=44.83$, $p<0.01$, respectively). As expected, performance was faster for L1 (722 ms) than L2 (813 ms) and faster for cognates (741 ms) than non-cognates (794 ms).[1] That is, we obtained a cognate facilitation effect. The significant interaction between language and cognate status ($F(1, 19)=11.62$, $p<0.01$; see also Fig. 3) reflected a larger cognate facilitation effect in L2 (81 ms) than L1 (25 ms). Individual comparisons revealed that the cognate facilitation effect was significant for L1 ($t(19)=2.33$, $p<0.05$) and for L2 ($t(19)=6.69$, $p<0.01$).

2.1.2. Mixed language condition: switch versus non-switch trials

The effect of language switching was tested by comparing trials from the same language as the previous trial (non-switch) with trials in which the language differed from the previous trial (switch). ANOVAs were carried out with type of trial (non-switch vs. switch), language (L1 vs. L2) and cognate status (cognate vs. non-cognate) as factors.

The analysis of naming latencies revealed a main effect for all three factors: type of trial ($F(1, 19)=75.10$, $p<0.01$), language ($F(1, 19)=27.33$, $p<0.01$) and cognate status ($F(1, 19)=78.34$, $p<0.01$). As expected, there were faster naming latencies for non-switch trials compared to switch trials (47 ms) and for

[1] This latter comparison includes different pictures; however, in delayed naming no difference between cognates and non-cognates was found, suggesting that there were no systematic differences between these two categories in terms of articulatory-phonetic encoding.

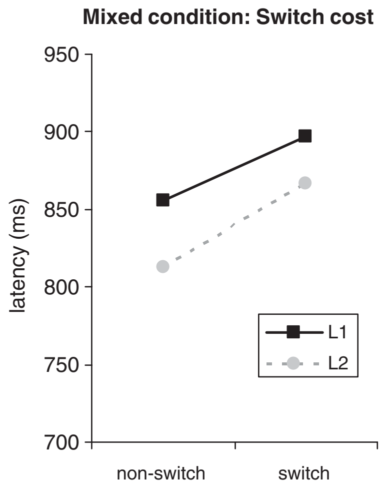

Fig. 1 – Naming latencies for non-switch trials and switch trials for L1 and L2 indicating the symmetric switch cost for L1 and L2.

cognates than non-cognate names (69 ms). Noteworthy is that on average faster naming latencies were obtained for L2 than L1 (37 ms). The main effects were qualified by two significant interactions. Interestingly, the interaction between language and cognate status ($F(1, 19) = 7.38$, $p < 0.05$) indicated that the cognate facilitation effect was larger for L1 (84 ms) than L2 (53 ms). The effect was nevertheless significant for both languages (L1: $t(19) = 9.68$, $p < 0.01$; L2: $t(19) = 5.0$, $p < 0.01$). The interaction between type of trial and cognate status ($F(1, 19) = 5.47$, $p < 0.05$) indicates that the cognate effect was larger for non-switch trials (79 ms) than switch trials (57 ms). *T*-tests showed that the cognate facilitation effect was significant for both types of trials (non-switch: $t(19) = 9.09$, $p < 0.01$; switch: $t(19) = 6.26$, $p < 0.01$, see also Fig. 3).

Note that a difference in magnitude of the switching cost per language is indicated by the interaction between language and type of trial. However, neither this interaction nor the three-way interaction between type of trial, language and cognate status was significant. In other words, we did not obtain evidence for asymmetric switching costs for the two languages. This is illustrated in Fig. 1, where the mean reaction times are plotted for switch and non-switch trials for each language.

2.1.3. *Comparison between blocked and mixed language conditions: context*

To investigate the effect of the mixed language context on L1 and L2, trials in blocked language conditions were compared to non-switch trials in mixed language conditions. ANOVAs were carried out with type of trial (blocked vs. non-switch trials), language (L1 vs. L2) and cognate status (cognate vs. non-cognate) as factors.

The ANOVAs revealed main effects of type of trial ($F(1, 19) = 8.95$, $p < 0.01$) with faster naming latencies for trials from blocked than mixed language conditions (67 ms), a marginally significant effect of language ($F(1, 19) = 3.68$, $p = 0.07$) and an effect of cognate status ($F(1, 19) = 80.72$, $p < 0.01$), reflecting a cognate facilitation effect.

A three-way interaction between type of trial, language and cognate status ($F(1, 19) = 18.55$, $p < 0.01$) qualified the significant two-way interactions between type of trial and language ($F(1, 19) = 33.89$, $p < 0.01$) as well as between type of trial and cognate status ($F(1, 19) = 11.2$, $p < 0.01$). The three-way interaction is visualized in Fig. 2. *T*-tests revealed significantly shorter naming latencies for non-switch trials from blocked compared to mixed language conditions for cognates as well as non-cognates in L1 (cognates: $t(19) = 3.78$, $p < 0.01$; non-cognates: $t(19) = 6.49$, $p < 0.01$). In L2, the difference between blocked and non-switch trials was not significant for either cognates or non-cognates. Clearly, the effect of type of trial was larger on L1 than L2 and interacted with cognate status in such a way that the effect of cognate status was larger rather than smaller for L1 than L2 in the switching context (see also Fig. 3).

In the blocked language conditions, a standard language effect was obtained with faster naming latencies for L1 than L2. In contrast, the analysis of the mixed language condition revealed faster reaction times for L2 than L1 in non-switch

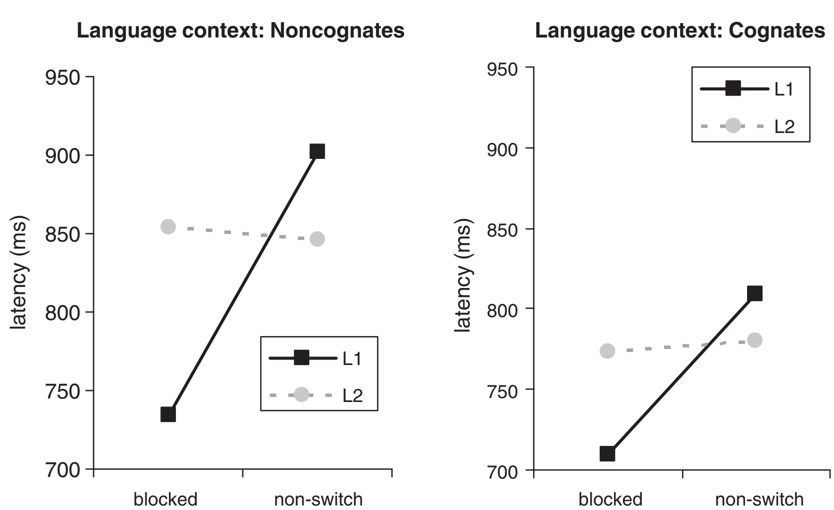

Fig. 2 – Naming latencies for blocked and non-switch trials for both languages for pictures with cognate names (left panel) and non-cognate names (right panel).

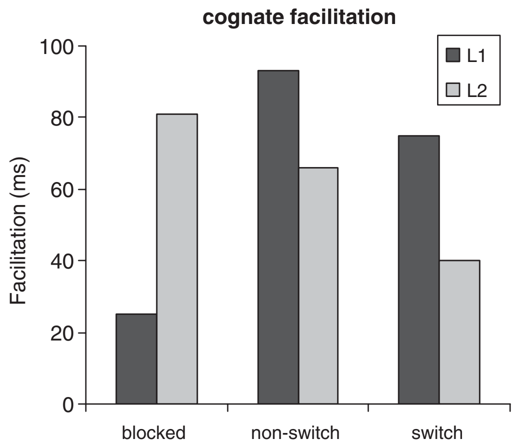

Fig. 3 – The cognate facilitation effect for all types of trials for both languages.

trials. These findings suggest that the mixed language context has a strong effect on L1 but hardly any effect on L2. Furthermore, we obtained the expected cognate facilitation effect in the blocked language conditions for both languages that was larger in L2 than L1. In the mixed language condition, these facilitative effects are sustained for both switch and non-switch trials, but now larger for L1 than L2. It appears that the mother tongue is not only slowed down under mixed language conditions but also is more open to influences of L2, as suggested by the larger cognate facilitation effect for L1 compared to L2. In Fig. 3, the effect of cognate status is plotted for all three trials types. Noteworthy is that no asymmetrical switching costs were obtained.

2.2. *Electrophysiological data*

The grand average waveforms for blocked, non-switch and switch trials are presented in Fig. 4. Target pictures elicited the N1–P2 complex typical for visually presented material. The P2 was followed by two negative components peaking at about 320 ms and 420 ms. In this study, we focused on these negative components. The first component may be similar to the N2, a fronto-central negativity. In language-related tasks, the N2 is observed relatively late, i.e., between 300 and 700 ms (see, e.g., Müller and Hagoort, 2006; Rodriguez-Fornells et al., 2005; Schiller, 2006; Schiller et al., 2003a,b, 2006; Schmitt et al., 2000, 2001). The functional significance of this component is not yet clear, but the amplitude of the N2 might be related to response inhibition or response conflict monitoring.

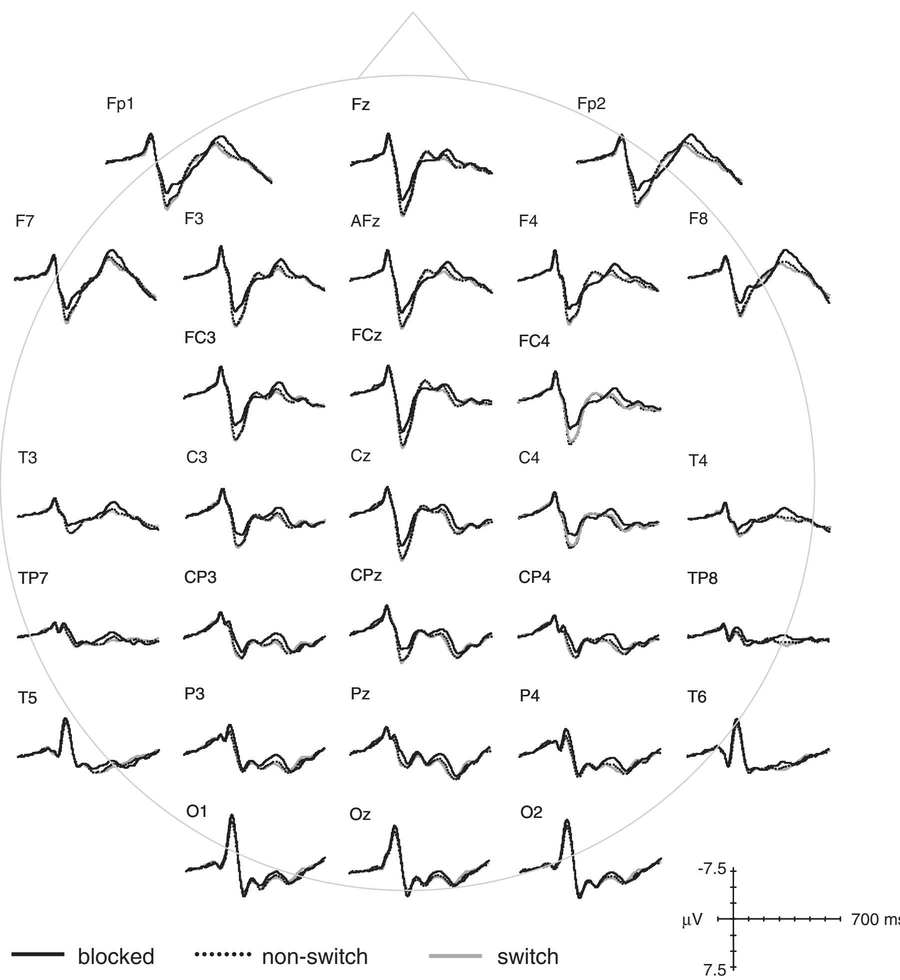

Fig. 4 – Grand average event-related potentials for blocked, non-switch and switch trials time-locked on the onset of the pictures. For these averages, trials were collapsed across language and cognate status.

In the analyses two time windows were used: 275–375 ms and 375–475 ms. Omnibus ANOVAs were run with type of trial (if relevant), language, cognate status and electrode site, followed by separate analyses per language. Where appropriate, topographic effects were explored by introducing hemisphere, laterality and (anterior–posterior) position as factors (for details, see Experimental procedures).

2.2.1. Blocked language condition

The analysis of the blocked language conditions allowed for the investigation of the neural correlates of the difference between L1 and L2 and between cognates and non-cognates. The grand average event-related potentials for L1 vs. L2 and for cognates vs. non-cognates time-locked to the onset of the pictures are shown in Fig. 5 for electrode Fz.

2.2.1.1. Time window 275–375 ms. In the omnibus ANOVA, a significant effect of cognate status was revealed ($F(1, 19)=4.56$, $p<0.05$), reflecting a more negative amplitude for cognates compared to non-cognates (0.41 μV). The interaction between language and electrode site was marginally significant ($F(1, 19)=2.80$, $p=0.053$). Planned analyses per language revealed no significant effects in either language.

2.2.1.2. Time window 375–475 ms. In the omnibus ANOVA, a main effect of language was found ($F(1, 19)=7.57$, $p<0.05$), reflecting an increased amplitude of the ERP waveform for L1 trials compared to L2 trials (0.75 μV). There was also a main effect of cognate status ($F(1, 19)=17.07$, $p<0.01$), indicating that the ERP in this time window was more negative for cognates compared to non-cognates (0.63 μV). Finally, the interaction between language and electrode site was significant ($F(1, 19)=5.47$, $p<0.01$). Separate analyses for each language revealed that for both L1 and L2 there was a significant effect of cognate status (L1: $F(1, 19)=16.75$, $p<0.01$; L2: $F(1, 19)=4.36$, $p<0.05$).

Topographic analyses revealed a significant interaction between language and position ($F(3, 17)=3.52$, $p<0.01$). This suggested that the language effect was largest over anterior relative to posterior sites. Cognate status did not interact with any of the topographic factors, suggesting that this effect is broadly distributed.

2.2.2. Mixed language condition: switch versus non-switch trials

The effect of language switching was tested by comparing trials from the same language as the previous trial (non-switch) with trials from a different language than the previous trial (switch) in the mixed language condition. The grand average event-related potentials for non-switch vs. switch trials in L1 and L2 are shown in Fig. 6A for electrode Fz.

2.2.2.1. Time window 275–375 ms. At this early time window, only a significant interaction between type of trial and language was observed ($F(1, 19)=5.51$, $p<0.05$). Planned ANOVAs per language revealed a significant effect of type of trial for L1 ($F(1, 19)=6.36$, $p<0.05$). This effect reflected an increased negativity of the ERP waveform for non-switch compared to switch trials (0.45 μV). For L2, no significant effects were obtained. The topographic maps in Fig. 5 visualize the difference of non-switch minus switch trials. The map for this time window illustrates the differential effect of type of trial in L1 and L2, which appears to be more negative for L1.

2.2.2.2. Time window 375–475 ms. The omnibus ANOVA revealed a main effect of type of trial ($F(1, 19)=6.03$, $p<0.05$), reflecting a more negative deflection (0.32 μV) of the ERP for non-switch as compared to switch trials. Furthermore, the three-way interaction between type of trial, language and electrode site reached significance ($F(28, 532)=3.19$, $p<0.05$). Finally, cognate status interacted marginally with electrode site ($F(1, 19)=2.28$, $p=0.09$). The ANOVA for L1 revealed a significant effect of type of trial ($F(1, 19)=5.66$, $p<0.05$) and an interaction of type of trial and electrode site ($F(28, 532)=2.96$, $p<0.05$). Again, for L2 no significant effects were obtained.

Topographic analyses showed three-way interactions of type of trial, language and position ($F(3, 57)=8.71$, $p<0.01$) and type of trial, language and hemisphere ($F(1, 19)=5.40$, $p<0.01$), suggesting a more frontal distribution of the effect of trial type in L1 and a more left-distributed effect in L2 (see Fig. 6A). Furthermore, cognate status interacted with laterality ($F(1, 19)=7.09$, $p<0.01$) and with laterality and position ($F(3, 57)=4.05$, $p<0.01$). Finally, an interaction of type of trial, language, cognate status, laterality and position ($F(3, 17)=$

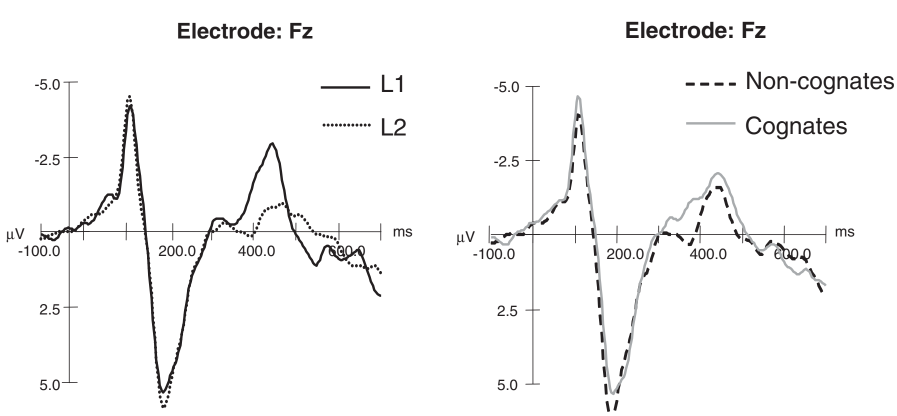

Fig. 5 – Grand average event-related potentials for blocked language conditions, for L1 and L2 (left panel) and for cognates and non-cognate pictures (right panel).

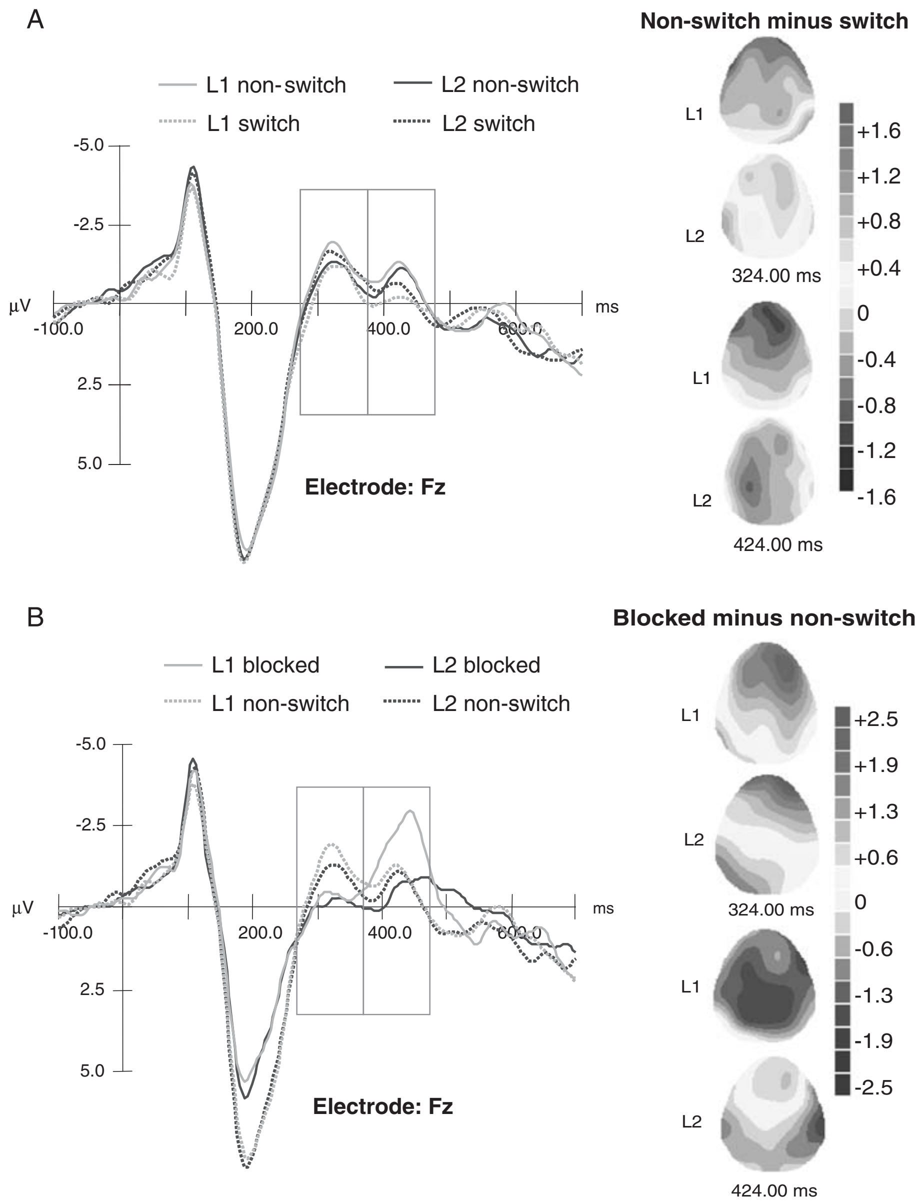

Fig. 6 – (A) Grand average ERP waveform for electrode site Fz for non-switch and switch trials for L1 and L2 (collapsed on cognate status). The time windows 275–375 ms and 375–475 ms that were used for statistical analyses are framed. Topographic maps of the difference waves, obtained by subtracting the non-switch ERPs from the switch trials ERPs, are shown for L1 and L2 for two time points from the middle of each time-window. (B) Grand average ERP waveform for electrode site Fz for blocked and non-switch trials for L1 and L2 (collapsed across cognate status). The time windows 275–375 ms and 375–475 ms that were used for statistical analyses are framed. Difference maps of blocked minus non-switch trials are shown for L1 and L2 for two time points taken from the middle of each time window.

3.89, $p<0.05$) suggested that cognate status modulated the distribution of the language and type of trial effects.

Taken together, in both time windows, for L1 but not for L2, we obtained a small but significant negative deflection for non-switch compared to switch trials.

2.2.3. *Comparison between blocked and mixed language conditions: context*

To investigate the effect of the mixed language context on L1 and L2, trials obtained under blocked conditions were compared to non-switch trials obtained under mixed language conditions. The grand average ERPs for blocked and non-switch trials in L1 and L2 are shown in Fig. 6B. Also, the topographic maps of the difference of blocked minus non-switch trials are depicted.

2.2.3.1. *Time window 275–375 ms.* The omnibus ANOVA revealed a significant interaction between type of trial and electrode site ($F(28, 532)=11.02$, $p<0.01$). Further, language interacted with electrode site ($F(28, 532)=4.43$, $p<0.01$). Finally, in this early time window a significant effect of cognate status was obtained ($F(1, 19)=6.43$, $p<0.05$) with larger amplitudes for cognates than for non-cognates (0.34 μV). In Fig. 7, the grand average ERPs are shown for cognates and non-cognates (collapsed across languages) to visualize this effect of cognate status.

There was no interaction between type of trial and language, indicating that the effect of type of trial did not significantly differ for L1 and L2. The topographic maps of the difference of blocked minus non-switch trials showed a similar pattern for both languages (Fig. 6B). Blocked trials resulted in smaller amplitudes of the ERP than non-switch trials. This pattern sustained in the planned analyses per language: for L1 and L2, significant interactions between type of trial and electrode site were obtained ($F(28, 532) = 5.95$, $p < 0.05$ and $F(28, 532) = 7.08$, $p < 0.01$, respectively). The main effect of cognate status approached significance in the analyses of L1 ($F(1, 19) = 3.08$, $p = 0.09$) and L2 ($F(28, 532) = 3.41$, $p = 0.08$).

Topographic effects were revealed by a type of trial by hemisphere ($F(1, 19) = 18.72$, $p < 0.01$), a type of trial by position ($F(3, 57) = 15.91$, $p < 0.01$) and a type of trial by hemisphere by laterality by position interaction ($F(3, 57) = 7.78$, $p < 0.01$), reflecting that the effect of type of trial was stronger at frontal, lateral and right sites (see also topographic maps in Fig. 6B). Further, language interacted with position ($F(3, 57) = 7.48$, $p < 0.01$) and with laterality $F(1, 19) = 7.02$, $p < 0.05$) suggesting that L1 was more frontally and medially distributed than L2.

2.2.3.2. *Time window 375–475 ms.* The omnibus ANOVA showed a main effect of type of trial ($F(1, 19) = 11.33$, $p < 0.01$), reflecting an increased negativity in this time window for blocked compared to mixed language conditions (0.83 μV). A main effect of language was found ($F(1, 19) = 4.68$, $p < 0.05$), revealing a more negative amplitude in this time window for L1 than L2 (0.40 μV). The effect of cognate status was significant ($F(1, 19) = 6.87$, $p < 0.05$), with a higher amplitude for cognates than for non-cognates (0.24 μV). Most interestingly, the interaction between type of trial and language was significant ($F(1, 19) = 4.40$, $p < 0.05$), indicating that the effect of

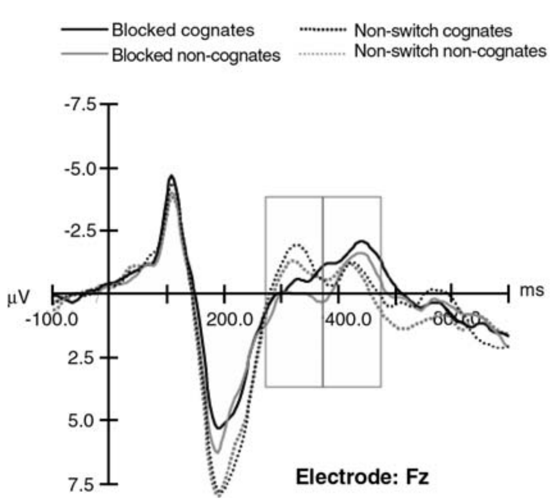

Fig. 7 – Grand average ERP waveform for electrode site Fz for blocked and non-switch trials for cognate and non-cognate words (collapsed across language). The time windows 275–375 ms and 375–475 ms that were used for statistical analyses are framed.

type of trial was different for L1 and L2. In Fig. 6B, the grand average ERPs of blocked and non-switch trials suggest that specifically for L1 blocked trials the ERP is more negative. The interactions between language and electrode site ($F(28, 532) = 6.02$, $p < 0.01$) and between cognate status and electrode site ($F(28, 532) = 2.66$, $p < 0.05$) were also significant. Finally, the interaction between type of trial, language and electrode site was marginally significant in this omnibus ANOVA ($F(28, 532) = 2.44$, $p = 0.07$). In separate analyses for L1, the ANOVA showed a main effect of type of trial ($F(1, 19) = 13.01$, $p < 0.01$) and of cognate status ($F(1, 19) = 7.46$, $p < 0.05$). In L2, no significant effects were obtained.

The interactions with electrode site were explored in topographic analyses which revealed interactions of language with position ($F(3, 57) = 10.25$, $p < 0.01$) and of type of trial, language and position ($F(3, 57) = 3.97$, $p < 0.05$), suggesting that the effect of language is stronger at frontal electrodes especially for blocked compared to non-switch trials. Furthermore, cognate status interacted with position ($F(3, 57) = 3.98$, $p < 0.05$), laterality ($F(1, 19) = 5.48$, $p < 0.05$) and with hemisphere and position, ($F(3, 57) = 3.69$, $p < 0.05$).

Thus, in the first time window, an increased negativity was found for non-switch trials compared to blocked trials irrespective of language. In contrast, in the second time window, only in L1 but not in L2 increased negativity was found for blocked compared to non-switch trials. Further, in both time windows cognate status and language effects were obtained.

3. Discussion

This study investigated behavioral and electrophysiological correlates of bilingual language control. It addressed sustained and transient components by comparing single (blocked) language with mixed language contexts and switch and non-switch trials during intentional switching between languages. Further, we investigated behavioral and electrophysiological correlates of the cognate facilitation effect in these contexts.

3.1. *The cognate facilitation effect*

The behavioral results revealed a cognate facilitation effect for all types of trials with faster naming latencies for cognates compared to non-cognates. This finding extends earlier research (Costa et al., 2000; Christoffels et al., 2003, 2006) in that even though the bilinguals in the present study were presumably less proficient than participants in earlier research, still a cognate facilitation effect was found even in their dominant language. Interestingly, the facilitation effect was larger for L1 than L2 in the mixed language condition and larger for L2 than L1 in the blocked language conditions. That is, the normal asymmetry between languages is reversed in mixed conditions. As suggested by Kroll et al. (2006), it appears that L1, normally fast and not much affected by the L2, is in mixed conditions far more open to influences from the L2. Cognate facilitation may serve as an index of how much the non-target language is activated and thereby influences processing in the target language. The electrophysiological data revealed a small but reliable difference between cognates and non-cognates in the blocked language condition. Enlarged negative amplitudes between 275 and 375 ms as well as between 375 and 475 ms after stimulus onset were found for cognates compared to non-cognates. In contrast to the reaction time data, this effect did not interact with language. Furthermore, although no significant effects of cognate status were obtained in the time windows reported for switch compared to non-switch trials, cognate effects were obtained for blocked versus non-switch trials, again with more negative amplitudes for cognates than for non-cognates.

Many psycholinguistic studies have found that cognate status influences performance on a range of language comprehension and production tasks. Bilingual speakers recognize cognates faster, translate and retrieve them more quickly than non-cognates (e.g., De Groot, 1992; De Groot and Nas, 1991; Gollan and Acenas, 2004). Recently, Kohnert (2004) reported that a bilingual aphasic patient named pictures with cognate names more accurately than pictures with non-cognate names. Although cognate status is an important factor influencing naming performance, only a few studies investigated the neural correlates of this effect, and we are not aware of any previous report of cognate effect in speech production using ERPs. As mentioned above, the effect in the electrophysiological data was relatively small, in contrast to robust effects in the behavioral data. In a recent PET imaging study (De Bleser et al., 2003), no clear differences were reported between L1 and L2 cognates and non-cognates other than an increased activation for L2 non-cognates over frontal and temporo-parietal areas. This may suggest that no strong differences in the substrates are involved.

Interestingly, the effect was already present in the earliest time window (275–375 ms). The stage of phonological code retrieval in word production has been estimated to take place between 275 and 400 ms (e.g., Indefrey and Levelt, 2004). Our data suggest that even in bilingual naming, which usually results in relatively long latencies, evidence for phonological processing may be found around that time interval. Alternatively, cognates may be qualitatively different represented in the brain than non-cognates, thereby affecting earlier stages in the speech production process (for a review on the cognate effect, see Costa et al., 2005).

As mentioned in the introduction, cognate facilitation can be most readily explained by accounts that incorporate partial activation of the non-target language's phonological forms, for example by assuming that phonological representation between languages are shared (Roelofs and Verhoef, 2006). If inhibition of the non-target language is assumed to take place at the lemma level, as is done in the IC model (Green, 1998), this implies that phonological activation will be restricted to the selected lexical node. Such a control mechanism has difficulties accounting for the cognate facilitation effect.

3.2. *Language control in language switching*

Large switching costs were found with longer naming latencies for switch compared to non-switch trials. Even though our participants were only moderately proficient, the switching costs were not larger for L1 than L2. We therefore obtained no evidence for reactive inhibition *as indicated by asymmetry across languages*. Hence, our results do not support this particular aspect of the IC model. As mentioned in the introduction, Costa and Santesteban (2004) concluded that highly proficient bilinguals have developed a language-specific selection mechanism because they did not find asymmetric switching costs for highly proficient bilinguals even when they were switching between their dominant L1 and their much weaker L3. Recently, Costa et al. (2006), extended these findings by showing that dissimilar languages, relative late age of language acquisition or switching between L2 and L3 yielded symmetric switching cost for highly proficient bilinguals. However, since participants in the present study were only moderately proficient, our results suggest that a high proficiency may not be a necessary prerequisite for symmetric switching costs. Participants were Germans who study in the Netherlands and are known to switch between their languages continuously in their daily lives (for details, see Experimental procedures). In a way, this environment provides a daily training in switching. Clearly, living in such a bilingual context may have increased their language control abilities. Indirect support for the idea that a bilingual environment may increase cognitive control abilities comes from work by Bialystok et al. (2004). Outside the language domain, bilinguals performed better than monolinguals at tasks measuring inhibitory control suggesting that bilingualism is associated with increased cognitive control abilities.

Language switching was also associated with a small modulation of the ERP amplitude in the time window between 275 ms and 375 ms post-stimulus onset. In contrast to the behavioral data, this effect was asymmetric across languages. In L1, the amplitude was enlarged for non-switch compared to switch trials, whereas in L2 no difference was found. Jackson et al. (2001) obtained an N2 for L2 switch trials, which they interpreted in terms of suppression of the stronger language. In our study, we obtained a modulation of the ERP as a result of language switching which might be similar to the N2. However, unexpectedly, we observed the most negative amplitude for non-switch rather than switch trials. This finding is not readily interpretable in terms of inhibition. A few issues are relevant concerning this point. First, the go/no-go N2 might not be comparable to the negativity that we and Jackson et al. (2001) observed, where participants were required to respond to every trial. Second, although the magnitude of the N2 is often taken to reflect the neural activity required for response inhibition, a reversed N2 with enlarged amplitudes for go trials compared to no-go trials has also been interpreted like the regular N2 (e.g., Kiefer et al., 1998; Schiller et al., 2003a). Third, recently, a conflict monitoring interpretation of the N2 has been favored, and the N2 has been shown to reverse depending on the proportion of go and no-go trials (e.g., Nieuwenhuis et al., 2003; Donkers and Van Boxtel, 2004). This suggests that the amplitude and direction of the N2 is very sensitive to context. Differences in experimental design may therefore result in different outcomes. For example, language switches in the Jackson et al. (2001) study were fully predictable, while they were unpredictable in the current study. The influence of predictability of language switches on the ERP components has yet to be established empirically. Further, Jackson et al. used digits in a delayed naming task, whereas in our study, participants responded normally, without delay, on a much larger (response) set of pictures. Delayed naming can be considered as a form of response withholding (i.e., inhibition) which may have interacted with language control in a way that modulated the ERPs. For example, it might be more difficult to withhold responding in the dominant language.

If the modulation of the amplitude of the ERP between 275 ms and 375 ms indeed reflected the amount of conflict processing in the different conditions, then a tentative explanation for the highest amplitude on L1 non-switch trials might be that participants were biased to respond in L2 in mixed language contexts, to facilitate responding in L2. When such a bias is present, L1 non-switch trials present a situation with relatively more conflict that might then be reflected by the increased amplitude of the N2 for non-switch trials.

Switching costs were also reflected in the ERP between 375 ms and 475 ms. This deflection may also resemble a component that has been related to conflict processing in the literature, particularly the N450 (e.g., West and Alain, 1999), a negative component peaking about 450 ms post-stimulus. Recently, it was elicited when inducing lexical conflict in monolinguals (Koppenhagen and Schiller, in preparation). In our study, the ERP in this time window was enlarged for non-switch rather than switch trials, suggesting that this component was mainly sensitive to the type of trial.

Taken together, we did not obtain asymmetric switching cost in the reaction time data and relatively small effects of switching in the ERP data. It appears that the effect of the mixed language context – discussed in the next section – on the base reaction time (i.e., the non-switch trials) is very strong. Also in the ERP data, effects of language mixing itself were much stronger than the differences between non-switch and switch trials. This may overrule more subtle switching cost differences that appear to depend on different factors, such as proficiency in language and experience in language switching (for a discussion of circumstances that reverse asymmetric switching costs outside the language domain, see Monsell et al., 2000).

3.3. *Language production in different language contexts*

The blocked language conditions revealed a standard effect of proficiency with faster naming latencies in L1 than in L2. This pattern reversed for the mixed language conditions. For non-switch and switch trials alike, naming latencies were faster in L2 than in L1. Noteworthy is that this effect of language mixing mainly had an impact on the mother tongue. Naming latencies in L2 remained more or less the same across blocked or mixed conditions, but in L1 they slowed down. Language context modulated the ERP waveforms stronger than language switching did. Here, an increased negativity was found for non-switch trials compared to blocked trials irrespective of language in the first time window (275 ms–375 ms). Interestingly, in the second time window (375 ms–475 ms) we found enlarged negative ERP amplitudes for blocked compared to mixed language conditions for L1 but not for L2. Indeed, for electrode Fz (Fig. 6B) in the earlier time window there is hardly any negativity apparent for blocked trials, whereas in the later time window the amplitude is clearly highest for blocked L1 trials. Given this qualitatively different pattern, it appears that both components are sensitive to different aspects of controlled production. The first component seems particularly sensitive to the language context, the sustained component of controlled language processing. The latter may distinguish the 'default' speech production condition (in L1 blocked trials) from the other conditions. For the later component, we found lowest amplitudes for switch trials, higher for non-switch trials and highest for L1 blocked trials. As mentioned in the previous section, the second component may be similar to the N450, which has been related to lexical conflict. It is unlikely that bilinguals experience more conflict in non-switch compared to switch trials and in blocked compared to mixed language conditions. Nevertheless, the sensitivity to type of trial suggests that the component in the second time window does reflect control in language processing.

As mentioned earlier, the behavioral as well as the electrophysiological data suggest that the mixed language context had a strong effect on L1 but not L2. The effect of cognate status on the L1 was greatly increased in mixed conditions but was similar on the L2 across conditions. In Fig. 8, the effects of context (i.e., blocked minus non-switch trials) are plotted to illustrate this more clearly. It appears that in mixed language conditions, bilinguals exercise language

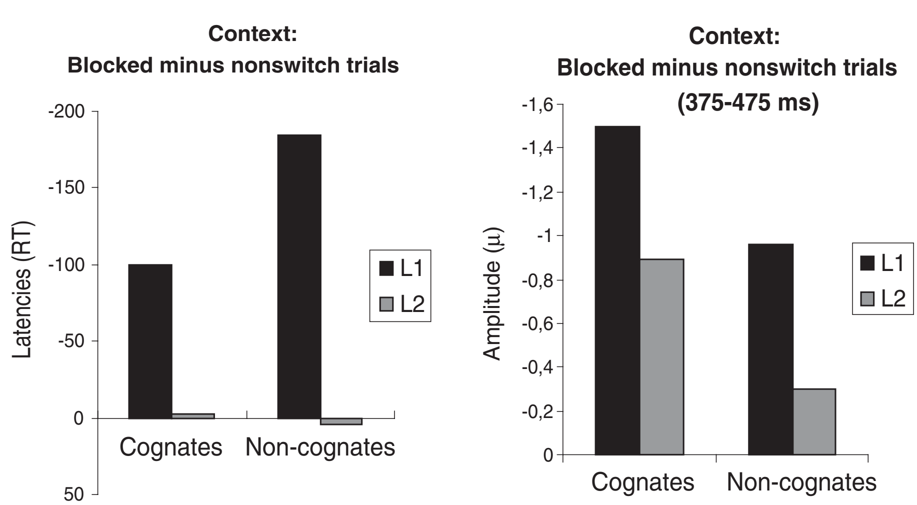

Fig. 8 – Magnitude of the mixed language context effect (mean difference between non-switch trials from blocked and mixed conditions) for L1 and L2 for reaction time data (upper panel) and grand average for the EEG data for time window 375–475 ms.

control mainly by (automatically) adjusting activation levels in the dominant first language rather than by also modulating the weaker second language. For L2, it did not have a large impact whether production takes place in a blocked or mixed context. For L1, the availability of lexical representations seems to be reduced in mixed compared to blocked language context to facilitate language production in L2.

One way of achieving this control may be by globally inhibiting the L1 (e.g., Grosjean, 1997; Paradis, 1997). This is functionally equivalent to selectively increasing the activation threshold of the L1 (Paradis, 1997, 2004). According to Grosjean (1997), bilinguals find themselves in a language mode continuum with a monolingual mode at one end and a bilingual mode at the other end. When bilinguals interact with monolinguals, they are in a monolingual mode in which the target language is active and the non-target language is (at least partially) deactivated. When bilinguals interact with others who share their languages, they are in a bilingual mode where both languages are relatively active. Our data suggest that when speaking only in the L2 or when speaking in a mixed language context, both languages were relatively active. However, the data also clearly suggest that modulation of the relative activation of the languages appears to take place mainly by adapting accessibility of the L1 rather than modulation of both the L1 and L2.

Lowering of L1 activation (raising its activation threshold) will result in a more balanced relative activation of L1 and L2, possibly giving advantage to the weaker language. Costa et al. (2006) observed that symmetric rather than asymmetric switching cost go together with slower latencies in L1 than L2. This was also the case for our participants. To explain the faster L2 than L1 latencies, Costa and colleagues put forward an account in terms of separate setting of activation thresholds of the two languages. However, they do not seem to take into account that more balanced activation levels will strongly influence switch costs since these are calculated by taking the difference between the base non-switch and switch latencies. Importantly, symmetric switch costs may not be taken as evidence for language selective selection of lexical items, as has been argued by Costa and colleagues. It is therefore premature to conclude that highly proficient bilinguals have developed a qualitatively different selection mechanism that is language-specific only based on the pattern of symmetric switch costs in highly proficient bilinguals.

In this respect, the present data are compatible with the idea that language task schemas as described in the IC model inhibit language in general. Indeed, Meuter (2005) suggested that the default setting of bilingual speakers in a bilingual context is to inhibit L1 to allow greater efficiency in L2 based on an increased error rate for L1 in a language switching task under conditions of increased vigilance. The suggestion that the reversed language effect reflects sustained language control is supported by the finding that the difference between L1 and L2 naming latencies was not affected by the amount of time given to prepare for the response language (Costa and Santesteban, 2004).

Proactive inhibition of L1 in a bilingual context does not necessarily have to imply that bilinguals rely on reactive inhibition per trial since presumably the language as a whole may be globally inhibited in mixed conditions (for a discussion of proactive and reactive inhibition, see also De Groot and Christoffels, 2006).

Note that this explanation is in line with the increased cognate facilitation effect for L1 in the mixed compared to the blocked language conditions. The change in baseline activation of L1 results in approximately equivalent levels of activation for both languages, or even a stronger activity for L2 in the mixed language conditions. This increases the opportunity of the weaker L2 to influence L1 processing, causing a larger cognate effect (c.f. Kroll et al., 2006).

3.4. Conclusion

Previous studies on bilingual language control mainly focused on language switching costs to assess language control in bilinguals. In the present study, we assessed the effect of the mixed language context as well as language switching costs. The cognate facilitation effect obtained for L1 and L2 indicated phonological activation of the non-response language. The effect of cognate status on the ERP waveform suggested that cognate status may be used as a marker investigating relative activation of the non-target language in real time. We obtained no switching cost asymmetry for L1 and L2 in the behavioral data, although participants were not particularly highly proficient. Our data therefore suggest that daily switching between languages may be an important factor in addition to language proficiency influencing language control and switching costs. Both the reaction time and the ERP data indicated that language mixing has a profound impact on L1 production but does not so much affect production in L2. L1 latencies are slowed down and the cognate facilitation effect for L1 is much larger in the mixed compared to the blocked language context. Also, modulation of ERP components occurred mainly in the L1. This pattern of results suggests that in mixed language contexts the level of activation of L1 might be reduced to facilitate language production in L2.

In sum, while our data suggest that global inhibition of languages plays an important role in language control, it is not entirely compatible with the idea of reactive inhibition of lexical items. How, then, are bilinguals able to respond in the target language in highly mixed contexts were presumably both languages are highly activated? A number of authors have suggested that language may be one of the properties that are specified in the conceptual message to determine specific activation of relevant items in the lexicon. That is, it is suggested that language-specific *activation* of specific lexical items (rather than of a whole language) is the mechanism by which the target item eventually receives most activation and therefore becomes selected (e.g., La Heij, 2005; Poulisse, 1997). Language-specific activation as the sole language control mechanism cannot easily account for findings such as the cognate facilitation effect which are compatible with language-non-specific activation. However, mechanisms of language control do not have to be mutually exclusive. Indeed, current evidence seems to favor a combination of proposed mechanisms. Language-selective activation is a plausible mechanism to induce transient intentional control on a trial-by-trial basis, whereas inhibitory mechanisms may relate to sustained automatic language-context effects. Noteworthy is that our results suggest that this global language control takes place by selective adjustment of availability of the L1 only, not by adapting the relative activation of both L1 and L2. It would be most interesting to further disentangle the neural correlates of sustained contextual and transient components of language control by manipulating the percentage of language switches parametrically.

4. Experimental procedures

4.1. *Participants*

Twenty-four undergraduate students of Maastricht University participated in the experiment (mean age: 23.6 years). They gave their written informed consent to their participation in the study, which has been approved by the Ethical Committee of the Psychology Faculty at Maastricht University. All participants were right-handed and had normal or corrected-to-normal vision. They were paid for their participation in the experiment. Four participants were excluded from the analysis due to technical failures or excessive movement artifacts in the EEG signal.

All participants were native German speakers. They learned Dutch in an intensive course before starting their undergraduate studies in the Netherlands. They studied in the Netherlands for at least 2 years (mean: 2.7) and usually lived in the Netherlands. Most classes at the university are in Dutch, teaching materials are in Dutch or English. In their daily lives, the participants typically speak Dutch at the university (inside and outside classes) although they typically socialize with other native German students (which account for 15% of the whole student population at Maastricht University) and therefore also frequently speak German during the day.

Their level of proficiency was assessed with a self-rating questionnaire and a vocabulary test based on lexical decision. Both tests were completed before the experiment. Participants rated their language proficiency in four domains (speech comprehension, speech production, reading and writing) on a 7-point scale (1 = very low, 7 = very high). Furthermore, the participants indicated how often they spoke each language on an average day. The mean scores for German and Dutch can be found in Table 2. Since all participants learned English at school, information on their English competence is also included in the Table. The proficiency test was a Dutch version of an English vocabulary test in the form of a non-speeded lexical decision task that was originally developed by Meara (1996) and adapted by Lemhöfer et al. (in preparation). It consisted of 60 items, i.e., 40 low-frequency words and 20 non-words. Participants were required to decide whether or not a presented letter string formed a correct Dutch word. Two ways of scoring as suggested by Lemhöfer et al. were employed: the mean percentage of correctly recognized words and correctly rejected non-words and Meara's *M* (Δ*M*). Δ*M* lies between 0 and 1 and represents the proportion of words within the given frequency range that is known by the participant. The results are summarized in Table 3.

Table 2 – Proficiency questionnaire

	German		Dutch		English	
	Mean	SD	Mean	SD	Mean	SD
Comprehension	6.9	0.3	5.2	1.15	5.1	1.04
Production	6.6	0.66	4.2	0.91	4.2	1.15
Reading	6.7	0.64	5.5	0.86	5.1	0.75
Writing	6.5	0.86	4.0	0.86	4.3	1.14
% daily use	66.97	19.67	23.42	13.31	9.62	13.75

Table 3 – Proficiency test

	Mean	SD
% correctly recognized words	52.63	14.74
% correctly rejected words	88.25	11.1
Mean of correct words and non-words	64.44	8.38
Δ*M*	0.31	0.18

4.2. *Materials*

Forty-eight pictures were selected from the Max Planck Institute for Psycholinguistics database and consisted of simple white-on-black line drawings. Half of the pictures had cognate names and the other half non-cognate names. The German and Dutch cognates and non-cognates were matched for number of phonemes, frequency and phonological onset category. Word frequency and length information is presented in Table 4. See Appendix A for the full list of stimuli. Furthermore, a delayed naming task was included in order to control for possible differences among targets in the different experimental conditions in triggering the voice-key. The delayed naming task was analyzed separately. The results showed a main effect of language that approached significance ($F(1, 19) = 3.18$, $p = 0.09$) with faster naming latencies for L1 (455 ms) as compared to L2 (472 ms). There was no effect of cognate status. The interaction between language and cognate status was not significant. These findings indicate that differences in naming latencies for cognates and non-cognates in the experimental conditions can neither be due to a difference in the accessibility of articulatory routines for cognates and non-cognates nor to differences in the way with which cognates and non-cognates trigger the voice-key.

4.3. *Design*

Three factors were manipulated in this study: language (German/Dutch), type of trial (blocked/non-switch/switch)

Table 4 – Stimulus characteristics

	Frequency (per 1 million words)		Number of phonemes	
	Mean	SD	Mean	SD
Picture names in L1 (German)				
Cognates	18.22	36.47	5.38	1.11
Non-cognates	26.42	28.98	4.76	1.49
Picture names in L2 (Dutch)				
Cognates	39.78	76.20	4.42	1.04
Non-cognates	38.50	36.04	4.00	1.12

Note. Frequencies were derived from the Celex database (Baayen et al., 1995).

and cognate status (cognate/non-cognate). Participants were asked to name pictures in their L1 (German) or L2 (Dutch) cued by the color (red or green) of the picture. The assignment of color cue to response language was counterbalanced across subjects. The experiment consisted of blocked and mixed language conditions. The blocked language conditions contained one task in each language, which consisted of two repetitions of 24 cognate and 24 non-cognate trials (i.e., 48 cognate trials and 48 non-cognate trials, in total 96 trials per language). Participants were required to name the pictures exclusively in their L1 or L2. Order of language was counterbalanced across participants.

In the mixed language conditions, the order of trials was manipulated such that switch trials (L1 to L2 and L2 to L1) and non-switch trials (L1 to L1 and L2 to L2) could be studied. The mixed language part consisted of 192 switch trials and 384 non-switch trials, of which a set of 192 non-switch trials was analyzed. Again, half of these trials were L1 and half L2 trials, half were cognates and half were non-cognates, resulting in 48 trials per condition. Furthermore, a set of 192 within-switch trials was included. These trials started like a non-switch trial, but after 250 ms the color of the picture changed. These trials were included for different purposes and not further analyzed in the present study. Within-switch trials were always followed by non-switch trials, which were excluded from the analysis. The mixed language condition trials were divided into 12 blocks, each containing 64 trials (resulting in 768 trials altogether). Order of the mixed language blocks was randomized across participants. Half of the blocks started with a non-switch trial in L1 and the other half with a non-switch trial in L2. The first trial was preceded by a filler picture to be able to define the first trial as a non-switch trial. In other respects, the order of switch and non-switch trials was unpredictable with a maximum of three subsequent trials of the same type.

4.4. *Procedure*

Participants were tested individually in a sound-attenuated and electrically shielded chamber. They were seated in front of a computer screen at a viewing distance of approximately 80 cm. The experimenter scored potential errors via loudspeakers in a separate room. During the naming blocks, a voice key was activated at picture onset to measure the naming latencies. A response was considered incorrect when a wrong picture name was produced, when the picture was produced in the wrong language or when the voice key was triggered incorrectly due to hesitations, stuttering or non-vocal responses. Invalid responses were excluded from the analysis.

Prior to the blocked language condition, participants were familiarized with the pictures. During familiarization, a single picture was presented on the screen with the designated name below the picture. Participants pressed a button to initiate the next trial. In the speeded naming block and the mixed language blocks, participants were asked to name the pictures as fast as possible. Each trial started with the presentation of a fixation cross in the center of the screen of a variable duration between 300 ms and 600 ms after which a single picture was presented on the screen. The duration of the fixation cross was varied so that subjects would not build up a systematic expectancy in form of a contingent negative variation (Walter et al., 1964). As soon as a response was given and the voice was triggered, the picture disappeared from the screen and after 1,500 ms the next trial started. If no response was recorded within 2,000 ms, the next trial started automatically. The delayed naming control task was similar to the experimental picture-naming task except that participants were told not to name the pictures before a fixation point appeared on the screen after a variable delay of between 1,000 ms and 1,800 ms.

4.5. *Apparatus, recording and data analyses*

The electroencephalogram (EEG) was recorded from 29 scalp sites (extended version of the 10/20 system) using tin electrodes mounted in an electrode cap. Electrode impedance was kept below 5 kΩ. Off-line analysis involved re-referencing of the scalp electrodes to the average activity of two electrodes placed on the left and right mastoids. Electrophysiological signals were amplified with a band pass filter of 0.05–30 Hz and digitized at 250 Hz. A bipolar montage placed on the left upper and lower orbital ridge monitored eye blinks and vertical eye movements. Lateral eye movements were measured with a bipolar montage placed on the right and left external cantus. Eye movements were recorded for later off-line rejection of contaminated trials. Epochs of 1,000 ms were obtained, including a 100-ms pre-stimulus baseline. Trials exhibiting activation on the scalp or eye-monitoring electrodes below −75 μV and above +75 μV were regarded as artifacts and removed from further analysis. Trials of correct responses were inspected visually. On average, 18.1% of the trials were excluded from further analysis (due to ERP artifacts or incorrect responses). There were no differences in the number of rejections between conditions. When executing a verbal response during recording of scalp EEG, the EEG may become contaminated by activity of articulatory muscles. However, artifacts are expected to occur only after the onset of the verbal response but not before the initiation of articulation. Therefore, we expected to obtain artifact-free ERPs before the onset of the verbal response, presumably reflecting speech planning. For the analysis of components that resembled the N2 complex, two 100-ms time windows analyses were determined after careful visual inspection of the grand average ERP waveforms: 275–375 ms and 375–475 ms. The mean amplitude values were calculated per participant and condition for both time windows.

Analyses of naming latencies were based on correct responses only. Reaction times shorter than 350 ms or longer than 1,500 ms were excluded from the analysis. Following these criteria, 6.5% (1.4% errors and 5.1% outliers) of the data points were excluded. No error analyses were carried out because the error percentages in the individual conditions were very low (<1.5%).

Both the behavioral data and the ERP waveforms were submitted to three analyses. First, in the blocked language conditions, analyses were conducted to replicate behavioral effects in this population and to establish possible basic effects of language and cognate status on the ERP waveforms in a single language context (1). The effect of language switching was addressed by comparing switch versus non-switch trials (2). Finally, the comparison of blocked versus non-switch trials reveals effects of a mixed language context (3).

First, an omnibus ANOVA was conducted that crossed the relevant factors of language (German, Dutch), type of trial and cognate status with the 29-level electrode factor (Fz, AFz, FCz, Cz, CPz, Pz, Oz, Fp1/2, F7/8, F3/F4, FC3/4, C3/4, CP3/4, P3/4, O1/2, T3/4, T5/6, TP7/8). In addition, planned comparisons were performed for each language separately to investigate effects of type of trial and cognate status (ANOVAs with type of trial, cognate status and electrode site). Scalp distribution effects were subsequently explored in ANOVAs using 16 electrodes where experimental factors (language, type of trial and cognate status) were crossed with three repeated measures: two levels of hemisphere (left vs. right), two levels of laterality (lateral vs. medial) and four levels of position (pre-frontal (Fp1, F3, F4, Fp2) vs. frontal (F7, FC3, FC4, F8) vs. parietal (TP7, P3, P4, T8) vs. occipital (T5, O1, O2, T6) (Federmeier and Kutas, 1999). In the analyses of the blocked language condition, there was no factor type of trial. For all analyses, the *p*-value was set at 0.05, corrected for deviations from sphericity (Greenhouse–Geisser epsilon correction).

Acknowledgments

This research was supported by grant no. 453-02-006 from the Netherlands Organization for Scientific Research (NWO) to Niels O. Schiller and grant no. 451-06-009 to I. K. Christoffels. The authors wish to thank Lesya Ganushchak, Iemke Horemans, Dirk Köster and Lourens Waldorp for helpful discussion.

Appendix A. Stimuli list

Cognates			Non-cognates		
L2	L1	English translation	L2	L1	English translation
appel	Apfel	'apple'	bord	Teller	'plate'
banaan	Banane	'banana'	broek	Hose	'trousers'
bezem	Besen	'besom'	eiland	Insel	'island'
bloem	Blume	'flower'	fornuis	Herd	'cooker'
pincet	Pinzette	'tweezers'	geit	Ziege	'goat'
boek	Buch	'book'	hek	Zaun	'fence'
boog	Bogen	'bow'	schaar	Schere	'scissors'
kat	Katze	'cat'	kast	Schrank	'cupboard'
heks	Hexe	'witch'	mier	Ameise	'ant'
karaf	Karaffe	'carafe'	kip	Huhn	'chicken'
bril	Brille	'glasses'	pak	Anzug	'suit'
hark	Harke	'rake'	ooievaar	Storch	'stork'
kraag	Kragen	'collar'	kikker	Frosch	'frog'
lamp	Lampe	'lamp'	trui	Pulli	'sweater'
libel	Libelle	'dragonfly'	slak	Schnecke	'snail'
loep	Lupe	'magnifying glass'	riem	Gürtel	'belt'
spiegel	Spiegel	'mirror'	rivier	Fluss	'river'
matras	Matratze	'mattress'	tent	Zelt	'tent'

Appendix A (*continued*)

Cognates			Non-cognates		
L2	L1	English translation	L2	L1	English translation
stempel	Stempel	'stamp'	peer	Birne	'pear'
meloen	Melone	'melon'	trein	Zug	'train'
net	Netz	'net'	krant	Zeitung	'newspaper'
paleis	Palast	'palace'	vlinder	Schmetterling	'butterfly'
pistool	Pistole	'pistol'	vork	Gabel	'fork'
wolk	Wolke	'cloud'	spuit	Spritze	'injection'

Note. Both in the cognate and non-cognate items, some show a cognate relation with English. Post hoc item analyses revealed no significant effects of relation to English as a background variable.

REFERENCES

Allport, A., Styles, E.A., Hsieh, S., 1994. Shifting attentional set: exploring the dynamic control of tasks. In: Umilta, C., Moscovitch, M. (Eds.), Attention and Performance XV: Conscious and Nonconscious Information Processing. MIT Press, Cambridge, MA, pp. 421–452.

Baayen, R.H., Piepenbrock, R., Gulikers, L., 1995. The CELEX Lexical Database [CD-ROM]. Linguistic Data Consortium, University of Pennsylvania, Philadelphia PA.

Bialystok, E., Craik, F.I., Klein, R., Viswanathan, M., 2004. Bilingualism, aging, and cognitive control: evidence from the Simon task. Psychol. Aging 19, 290–303.

Braver, T.S., Reynolds, J.R., Donaldson, D.I., 2003. Neural mechanisms of transient and sustained cognitive control during task switching. Neuron 39, 713–726.

Chen, H.C., Leung, Y.S., 1989. Patterns of lexical processing in a nonnative language. J. Exp. Psychol. Learn. 15, 316–325.

Christoffels, I.K., De Groot, A.M.B., Waldorp, L.J., 2003. Basic skills in a complex task: a graphical model relating memory and lexical retrieval to simultaneous interpreting. Bilingualism: Lang. Cogn. 6, 201–211.

Christoffels, I.K., De Groot, A.M.B., Kroll, J.F., 2006. Memory and language skills in simultaneous interpreters: the role of expertise and language proficiency. J. Mem. Lang. 54, 324–345.

Colomé, A., 2001. Lexical activation in bilinguals' speech production: language-specific or language independent? J. Mem. Lang. 45, 721–736.

Costa, A., 2005. Lexical access in bilingual production. In: Kroll, J.F., De Groot, A.M.B. (Eds.), Handbook of Bilingualism: Psycholinguistic Approaches. Oxford University Press, New York, pp. 308–325.

Costa, A., Santesteban, M., 2004. Lexical access in bilingual speech production: evidence from language switching in highly proficient bilinguals and L2 learners. J. Mem. Lang. 50, 491–511.

Costa, A., Caramazza, A., Sebastián-Gallés, N., 2000. The cognate facilitation effect: implications for models of lexical access. J. Exp. Psychol. Learn. 26, 1283–1296.

Costa, A., Santesteban, M., Caño, A., 2005. On the facilitatory effects of cognates in bilingual speech production. Brain and Lang. 94, 94–103.

Costa, A., Santesteban, M., Ivanova, I., 2006. How do highly proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. J. Exp. Psychol. Learn. 32, 1057–1074.

De Bleser, R., Dupont, P., Postler, J., Bormans, G., Speelman, D., Mortelmans, L., Debrock, M., 2003. The organisation of the bilingual lexicon: a PET study. J. Neurolinguist. 16, 439–456.

De Groot, A.M.B., 1992. Determinants of word translation. J. Exp. Psychol. Learn. 18, 1001–1018.

De Groot, A.M.B., Nas, G.L., 1991. Lexical representation of cognates and noncognates in compound bilinguals. J. Mem. Lang. 30, 90–123.
De Groot, A.M.B., Christoffels, I.K., 2006. Language control in bilinguals: monolingual tasks and simultaneous interpreting. Bilingualism: Lang. Cogn. 9, 189–201.
Donkers, F.C., Van Boxtel, G.J., 2004. The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. Brain Cogn. 56, 165–176.
Dove, A., Pollmann, S., Schubert, T., Wiggins, C.J., Von Cramon, D.Y., 2000. Prefrontal cortex activation in task switching: an event-related fMRI study. Brain Res. Cogn. Brain Res. 9, 103–109.
Fabbro, F., Skrap, M., Aglioti, S., 2000. Pathological switching between languages after frontal lesions in a bilingual patient. J. Neurol. Neurosurg. Psychiatry 68, 650–652.
Federmeier, K., Kutas, M., 1999. A ros by any other name: long-term memory structure and sentence processing. J. Mem. Lang. 41, 469–495.
Gollan, T.H., Acenas, L.R., 2004. What is a TOT? Cognate and translation effects on tip-of-the-tongue states in Spanish–English and Tagalog–English bilinguals. J. Exp. Psychol. 246–269.
Green, D.W., 1998. Mental control of the bilingual lexico-semantic system. Bilingualism: Lang. Cogn. 1, 67–81.
Grosjean, F., 1997. Processing mixed language: issues, findings and models. In: De Groot, A.M.B., Kroll, J.F. (Eds.), Tutorials in Bilingualism: Psycholinguistic Perspectives. Lawrence Erlbaum Associates, Mahawa, NJ, pp. 225–254.
Hermans, D., Bongaerts, T., De Bot, K., Schreuder, R., 1998. Producing words in a foreign language: can speakers prevent interference from their first language? Bilingualism: Lang Cogn. 1, 213–229.
Hernandez, A.E., Martinez, A., Kohnert, K., 2000. In search of the language switch: an fMRI study of picture naming in Spanish–English bilinguals. Brain Lang. 73, 421–431.
Hernandez, A.E., Dapretto, M., Mazziotta, J., Bookheimer, S., 2001. Language switching and language representation in Spanish–English bilinguals: an fMRI study. NeuroImage 14, 510–520.
Indefrey, P., Levelt, W.J.M., 2004. The spatial and temporal signatures of word production components. Cogn. 92, 101–144.
Jackson, G.M., Swainson, R., Cunnington, R., Jackson, S.R., 2001. ERP correlates of executive control during repeated language switching. Bilingualism: Lang. Cogn. 4, 169–178.
Jodo, E., Kayama, Y., 1992. Relation of a negative ERP component to response inhibition in a Go/No-go task. Electroencephalogr. Clin. Neurophysiol. 82, 477–482.
Kiefer, M., Marzinzik, F., Weisbrod, M., Scherg, M., Spitzer, M., 1998. The time course of brain activations during response inhibition: evidence from event-related potentials in a go/no go task. NeuroReport 9, 765–770.
Kohnert, K., 2004. Cognitive and cognate-based treatments for bilingual aphasia: a case study. Brain Lang. 91, 294–302.
Konishi, S., Jimura, K., Asari, T., Miyashita, Y., 2003. Transient activation of superior prefrontal cortex during inhibition of cognitive set. J. Neurosci. 23, 7776–7782.
Koppenhagen, H., Schiller, N.O., in preparation. Lexical conflict during overt picture naming: EEG and fMRI evidence.
Kroll, J.F., Bobb, S.C., Wodniecka, Z., 2006. Language selectivity is the exception, not the rule: arguments against a fixed locus of language selection in bilingual speech. Bilingualism: Lang. Cogn. 9, 119–135.
La Heij, W., 2005. Selection processes in monolingual and bilingual lexical access. In: Kroll, J.F., De Groot, A.M.B. (Eds.), Handbook of Bilingualism: Psycholinguistic Approaches. Oxford Univ. Press, New York, pp. 289–307.
Lemhöfer, K., Spalek, K., Schriefers, H., in preparation. Cross-language effects of grammatical gender on word production and recognition in bilinguals.
Levelt, W.J.M., Roelofs, A., Meyer, A.S., 1999. A theory of lexical access in speech production. Behav. Brain Sci. 22, 38–75.
Meara, P., 1996. English Vocabulary Test 10K. Centre for Applied Language Studies, University of Wales, Swansea, U.K.
Meuter, R.F.I., 2005. Language selection in bilinguals: mechanisms and processes. In: Kroll, J.F., De Groot, A.M.B. (Eds.), Handbook of Bilingualism: Psycholinguistic Approaches. Oxford Univ. Press, New York, pp. 349–370.
Meuter, R.F.I., Allport, A., 1999. Bilingual language switching in naming: asymmetrical costs of language selection. J. Mem. Lang. 40, 25–40.
Meuter, R.F.I., Humphreys, G.W., Rumiati, R.I., 2002. Bilingual language switching and the frontal lobes: modulatory control in language selection. Int. J. Biling. 6, 109–124.
Monsell, S., Yeung, N., Azuma, R., 2000. Reconfiguration of task-set: is it easier to switch to the weaker task? Psychol. Res. 63, 250–264.
Müller, O., Hagoort, P., 2006. Access to Lexical information in language comprehension: semantics before syntax. J. Cogn. Neurosci. 18, 84–96.
Nieuwenhuis, S., Yeung, N., Van den Wildenberg, W., Ridderinkhof, K.R., 2003. Electrophysiological correlates of anterior cingulate function in a go/no-go task: effects of response conflict and trial type frequency. Cogn. Affect. Behav. Neurosci. 3, 17–26.
Paradis, M., 1997. The cognitive neuropsychology of bilingualism. In: De Groot, A.M.B., Kroll, J.F. (Eds.), Tutorials in Bilingualism. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 331–354.
Paradis, M., 2004. A Neurolinguistic Theory of Bilingualism. John Benjamins Publishing Company, Amsterdam.
Pfefferbaum, Ford, Weller, Kopell, 1985. ERPs to response production and inhibition. Electroencephalogr. Clin. Neurophysiol. 60, 423–434.
Philipp, A.M., Gade, M., Koch, I., 2006. Inhibitory processes in language switching: evidence from switching language-defined response sets. Eur. J. Cogn. Psychol. 18, 624–639.
Potter, M.C., So, K.F., Von Eckardt, B., Feldman, L.B., 1984. Lexical and contextual representation in beginning and more proficient bilinguals. J. Verbal Learn. Verbal Behav. 23, 23–28.
Poulisse, N., 1997. Language production in bilinguals. In: De Groot, A.M.B., Kroll, J.F. (Eds.), Tutorials in Bilingualism. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 201–224.
Rodriguez-Fornells, A., Van der Lugt, A., Rotte, M., Britti, B., Heinze, H.J., Münte, T.F., 2005. Second language interferes with word production in fluent bilinguals: brain potential and functional imaging evidence. J. Cogn. Neurosci. 17, 422–433.
Roelofs, A., 1998. Lemma selection without inhibition of languages in bilingual speakers. Bilingualism: Lang. Cogn. 1, 94–95.
Roelofs, A., 2003. Shared phonological encoding processes and representations of languages in bilingual speakers. Lang. Cogn. Processes 18, 175–204.
Roelofs, A., Verhoef, K., 2006. Modeling the control of phonological encoding in bilingual speakers. Bilingualism: Lang. Cogn. 9, 167–176.
Schiller, N.O., 2006. Lexical stress encoding in single word production estimated by event-related brain potentials. Brain Res. 1112, 201–212.
Schiller, N.O., Bles, M., Jansma, B.M., 2003a. Tracking the time course of phonological encoding in speech production: an event-related brain potential study. Brain Res. Cogn. Brain Res. 17, 819–831.
Schiller, N.O., Münte, T.F., Horemans, I., Jansma, B.M., 2003b. The influence of semantic and phonological factors on syntactic decisions: an event-related brain potential study. Psychophysiology 40, 869–877.
Schiller, N.O., Schuhmann, T., Neyndorff, A.C., Jansma, B.M., 2006. The influence of semantic category membership on syntactic

decisions: a study using event-related brain potentials. Brain Res. 1082, 153–164.
Schmitt, B.M., Münte, T.F., Kutas, M., 2000. Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming. Psychophysiology 37, 473–484.
Schmitt, B.M., Rodriguez-Fornells, A., Kutas, M., Münte, T.F., 2001. Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words. Neurosci. Res. 41, 293–298.
Sohn, M.H., Ursu, S., Anderson, J.R., Stenger, V.A., Carter, C.S., 2000. The role of prefrontal cortex and posterior parietal cortex in task switching. Proc. Natl. Acad. Sci. U. S. A. 97, 13448–13453.
Thorpe, S., Fize, D., Marlot, C., 1996. Speed of processing in the human visual system. Nature 381, 520–522.
Walter, W.G., Cooper, R., Alridge, V.J., McCallum, W.C., Winter, A.L., 1964. Contingent negative variation: an electric sign of sensory motor association and expectancy in the human brain. Nature 203, 380–384.
West, R., Alain, C., 1999. Event-related neural activity associated with the Stroop task. Brain Res. Cogn. Brain Res. 8, 157–164.