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ERP correlates of a receptive language-switching task

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Previous research has shown large response time costs (in excess of 50 ms) when bilingual speakers switch predictably back and forth between naming items (a productive switching task) in their first (L1) and second languages (L2). A recent study using event-related potentials (ERPs) has shown that switching between languages is associated with activity over frontal (N2) and parietal (late positive complex) areas of cortex (Jackson, Swainson, Cunnington, & Jackson, 2001). Switching between naming in different languages requires a switch in both language representations and language-specific motor responses. The current study investigated a receptive (input) language-switching task with a common manual response. Number words were presented in L1 and L2, and participants were required to judge whether the words were odd or even (a parity judgement). Response costs were considerably reduced, and the frontal and parietal switch related activity reported in the productive switching task was absent. Receptive switching was associated with early switch-related activity over central sensors that were not language specific. These results are discussed in relation to the idea that there is no language-specific lexical selection mechanism. Instead the costs of receptive language switching may arise from outside the bilingual lexicon.

A key aspect of higher cortical function is the ability to switch effectively between alternative behavioural responses where this is appropriate (Drewe, 1974). Bilingual speakers provide us with a naturally occurring example of response switching, as during the course of a conversation, a bilingual speaker may switch back and forth between languages depending on the preferred language of the listeners.

Although switching between languages may appear effortless, experimental studies of language switching suggest that there is a measurable response time cost associated with switching between languages, at least for language production tasks. For example, when presented with a list of words in mixed languages, bilingual speakers are slower to read the list,

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compared to reading a word list in a single language (Dalrymple-Alford, 1985). However, assessing the cost of language switching, by comparing a block of single-language trials with a block of mixed-language trials is not ideal (Rogers & Monsell, 1995). This is because there are many differences between these conditions (for example they differ in terms of level of difficulty, with one condition involving a single task and the other two tasks). A better assessment of performance is achieved by comparing performance within a single block of trials. For example, items can be classified according to whether they are preceded by an item in the same language (nonswitch trial) or a different language (switch trial). This method confirms that switching between languages results in measurable costs for productive language-switching tasks, even when the switch is predicable. For example, it has been shown that bilingual speakers are slower to name items on switch trials than on nonswitch trials (Jackson, Swainson, Cunnington, & Jackson, 2001; Meuter & Allport, 1999).

We recently examined the time course of language switching in bilingual speakers using dense sensor EEG recording techniques during a predictable switching task (Jackson et al., 2001). We found that language switching was associated with a modulation of event-related potential (ERP) components over both frontal (N2) and parietal sensor sites. Over frontal sensor sites, switch trials were associated with an increased N2 negativity compared with nonswitch trials. However, this effect was found only for second-language (L2) trials, and there was no significant difference between switch and nonswitch trials for first language (L1). In contrast the parietal ERP modulation was not language specific, and it consisted of an increase in the magnitude of the late positive complex (LPC) between 350 ms and 700 ms after stimulus onset for switch trials compared with nonswitch trials.

We proposed that the frontal modulation of the N2 component might reflect the suppression of the habitual response (L1) during L2 switch trials (Meuter & Allport, 1999). Since most bilingual speakers are not equally competent in both languages, inhibitory processes may be most active on L2 trials following an L1 trial (i.e., on L2 switch trials). Increased N2 negativity has previously been reported during response suppression (Jackson, Jackson, & Roberts, 1999; Sasaki, Gemba, & Tsujimoto, 1989). This effect is also consistent with other forms of response competition—for example, during Stroop interference when the habitual response of reading the word has to be suppressed, and the ink colour of the word has to be named (Liotti, Woldorf, Perez, & Mayberg, 2000). This interpretation of the N2 effect for L2 switch trials is compatible with Green's Inhibitory Control Model of language switching (Green, 1998). Green proposed that selection of the appropriate item in the lexicon is achieved by active inhibition of the task-irrelevant language. The greater the task-irrelevant activity the greater the level of inhibition required.

The second switch-related modulation that we observed in the earlier study was a late and sustained increase in the positivity of the LPC for switch trials over bilateral parietal sensor sites. We interpreted this activity as reflecting the reconfiguration of the stimulus-to-response mappings. Each stimulus used in the task was uniquely mapped onto a response according to an arbitrary colour rule (name the digit in L1 if one colour, or in L2 if the other colour). Thus participants switched back and forth between language-specific phonology-to-articulatory sets on the basis of a colour cue, which changed predictably. Our finding of switch-related activity over parietal sensors is consistent with evidence from a recent PET (positron emission tomography) study, which implicated the parietal cortex, specifically the supramarginal gyri bilaterally, in switching between different languages (Price, Green, & von Studnitz, 1999).

Price et al. interpreted this activity as reflecting switching between different language-specific orthography-to-phonology mappings.

In the current study we focus on the behavioural costs and ERPs associated with a receptive (input) switching task rather than a productive (output) switching task. In the digit-naming study switching between different language-specific motor responses was an integral part of the task. Consequently the costs associated with switching between languages could result from switching between language representations and/or the cost of switching between alternative stimulus-to-response mappings. The productive cost of language switching was removed in the current study by making the response orthogonal to the language switch. We presented number words in two languages, and participants made the same parity judgement (whether an item was odd or even), indicated by a common response (e.g., press the left key for odd numbers and the right key for even numbers), regardless of the language of the item. Consequently, language switching was at a receptive level only, and input language was nominally irrelevant to the task.

Many models of the bilingual lexicon system suggest that there is a language-specific lexical selection mechanism. On switch trials this mechanism deactivates, or at least suppresses, the lexicon of the inappropriate language (e.g., Dijkstra & Van Heuven, 1998; Grainger & Dijkstra, 1992; Green, 1998). Selective lexical access applies to both productive and input switching tasks. However, evidence in support of this mechanism for tasks involving comprehension is mixed. While switch costs are found for bilingual lexical decision tasks (Grainger & Beauvillian, 1987; Thomas & Allport, 2000; von Studnitz & Green, 1997), studies of semantic categorization have generally found no effects of switching language (Caramazza & Brones, 1980; Potter, So, von Eckhardt, & Feldman, 1984). However, the latter studies may not be regarded as decisive on this issue as they were not specifically designed to look for switch costs. Von Studnitz and Green recently assessed switching costs in a semantic categorization task and found small but significant switch costs (von Studnitz & Green, 2002).

We therefore predicted that in the current study we would find a significant response cost associated with switch trials compared with nonswitch trials. We also predicted that removing the productive language element should eliminate the modulation of the LPC for switch trials, observed in our previous naming study. Finally we predicted that the N2 modulation effect would be present as the need to suppress the prepotent L1 should still be presented if selecting an L2 item from the lexicon activated the equivalent L1 response.

Methods

Subjects

A total of 21 native English speakers (mean age = 21.6 years, range = 20–34 years) were recruited according to the criteria that English was their first language (L1) and that they felt able to name the digits 1 to 10 fluently in a second language (L2). The mean parity judgement times obtained from the blocks of trials where only one language was presented were 601 ms for L1 words and 634 ms for L2 words. Data from 2 subjects had to be excluded because of eye blink artefacts (see ERP analysis below); an additional subject's data were excluded to recounterbalance, leaving a total of 18 subjects. These subjects used the following second languages: French ($n = 11$), German ($n = 4$), or Spanish ($n = 3$). A similar mix of languages was used in the earlier naming study (Jackson et al., 2001). The majority of subjects ($n = 11$) acquired their second language at secondary school age (13–18 years); 5 subjects acquired their second language between the ages of 7 and 12 years, 2 prior to age 6, and 1 during adulthood. Reading proficiency in English and L2 were self-rated on a 7-point scale (1 = very poor; 7 = highly proficient): Average proficiency in L1 was 6.8 (range = 6–7) compared with a mean of 3.4 (range = 2–5) for L2. The inclusion criterion for the current study was the same as that for the earlier naming study (Jackson et al., 2001), and the self-rated proficiency and age of acquisition of L2 was very similar to those in the previous study.

Procedure

Participants viewed stimuli projected onto a screen from a distance of 2.2 m. Each trial began with a central fixation mark, which was replaced by the first stimulus after 1500 ms. Stimuli were number words (1–4 and 7–9), presented one at a time in the centre of the screen (digits 5 and 6 were not included because of technical limitations on displaying the umlaut needed for the German word "fünf" and because the word for the number six is spelled the same way in both English and French). All words began with an upper case character (as demanded by German) and completed in the lower case. The visual angle of stimuli measured between 2.45° and 3° vertically and between 1.1° and 11.6° horizontally (depending on the particular digit/word). Stimuli were coloured yellow against a dark blue background, for high definition in a dimmed room.

Subjects were required to press a button with one index finger to indicate that an odd number was present and the other index finger to indicate even numbers; this mapping was counterbalanced across subjects. Response buttons were spaced 4" apart and a comfortable distance in front of the subject. Instructions were to respond as fast as possible whilst minimizing errors. Stimulus offset occurred 500 ms after response (or, in the absence of a response, after a maximum of 1500 ms). The next stimulus onset was after a random 1–2-s interval; response–stimulus intervals therefore ranged from 1.5–2.5 s. Response times were determined from the onset of the visual stimulus until the button-press.

Subjects first completed a practice block (48 trials), with digits being displayed rather than number words, to familiarize the subjects with the odd/even, left/right button-press mapping. Two "pure" blocks (64 trials each), one for each language, were presented both at the start and at the end of the experimental task. Within pure blocks, all words presented were from just L1 or L2. The main part of the task consisted of eight "mixed" blocks (64 trials per block, with a 15-s break between each block after which the subject pressed a button to continue with the next block). In mixed blocks, the word presented was

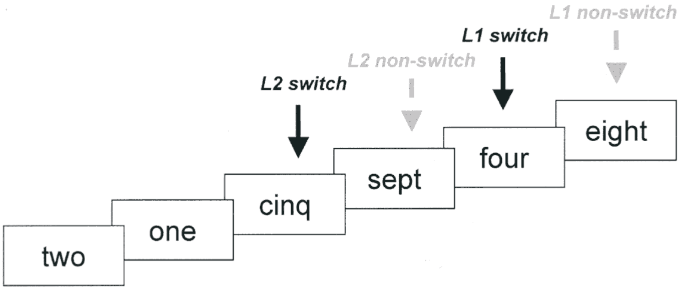


Figure 1. Trial ordering for the parity judgement task. Single number words were presented singly at the centre of the computer screen, and participants were asked to make an odd/even judgement on the number as quickly as possible by pressing a button with either index finger. (Odd/even: left/right index finger mappings were counterbalanced across subjects.) Number words were presented in sequences of alternating runs containing two trials in each language; the first trial in each run would involve a language switch. Response–stimulus interval varied randomly between 1.5 and 2.5 s.

from either L1 or L2. Mixed-block trials followed a fully predictable sequence of two-trial alternating runs—that is, two consecutive trials with L1 words followed by two consecutive trials with L2 words, and so on, with a language switch required every second trial (see Figure 1). The ordering of blocks (pure-L1, pure-L2, mixed, pure-L2, pure-L1; or pure-L2, pure-L1, mixed, pure-L1, pure-L2) was counterbalanced across subjects.

ERP recording

High-density ERPs were recorded from each participant using a 128-channel geodesic sensor net coupled to a high-input impedance amplifier (Tucker, Liotti, Potts, Russell, & Posner, 1994). EEG was continuously recorded and digitized at 250 Hz. Wherever possible, impedances were reduced to <50 kΩ prior to recording; where this level could not be attained by adjusting or rewetting the sensor with electrolyte solution, and where this led to noisy recordings, the sensor was excluded before analysis (see below). The continuous EEG was then segmented into 1-s epochs, time locked to the onset of each visual stimulus and commencing 100 ms prior to stimulus onset. Trials where the subject's response was incorrect, absent, or early (within 200 ms of stimulus onset), and trials containing eye movement artefacts (i.e., an EOG channel difference greater than 70 μV), or trials containing more than 10 bad channels (channels with voltage amplitudes over 200 μV or a change in amplitude between adjacent samples of more than 100 μV) were rejected from the dataset prior to averaging. Channels that were bad for more than 25% of trials for a given participant were excluded from all analyses. Two or fewer channels were rejected per subject. The average number of trials retained per subject was 92% (range 84–98%). ERPs were transformed using an average reference transform and low-pass filtered with a cut-off frequency of 45 Hz. The epoch was baseline corrected using data from the 100 ms prior to stimulus onset.

Behavioural data analyses

Response time (RT) data were analysed by repeated measures analysis of variance (ANOVA). The index of variation used in the figures is the standard error of the difference between means (*SED*). It is calculated using the formula: $SED = \sqrt{(2*MSE)/n}$, where MSE = mean square for the error term of the interaction, and n = number of observations (Cochran & Cox, 1957). Error data (calculated as the proportion of total trials given in that condition on which an error was made) were analysed using the Wilcoxon signed-rank test.

ERP data analyses

Two types of analysis were conducted on the ERP data. The first was designed to follow up on the results of our previous study of language switching using a digit-naming paradigm (Jackson et al., 2001), in order to identify whether the same effects would be present in the parity judgement paradigm. Therefore the same groups of sensors were analysed over the same (or analogous) time-points/time-ranges as had previously been found to be sensitive to differences between switch and nonswitch trials. The particular sensors used for these a priori comparisons (left fronto-central quadrant and Pz) are shown in Figure 2. *T* tests were carried out at each time point for the comparisons of interest, and significant samples are shown in figures as shaded areas between waveforms. The second analysis was a data-driven exploration of language-switching effects. Since the main interest of this investigation was "exogenous", or stimulus-driven, components of language switching, we were only interested in differences occurring before the time of most responses; a threshold of 500 ms after stimulus onset was therefore used, although the entire epoch (–100 ms to +900 ms) is displayed in figures for completeness. Waveforms for the switch and nonswitch (collapsed across L1 and L2) conditions were plotted on the 10–20 system, and

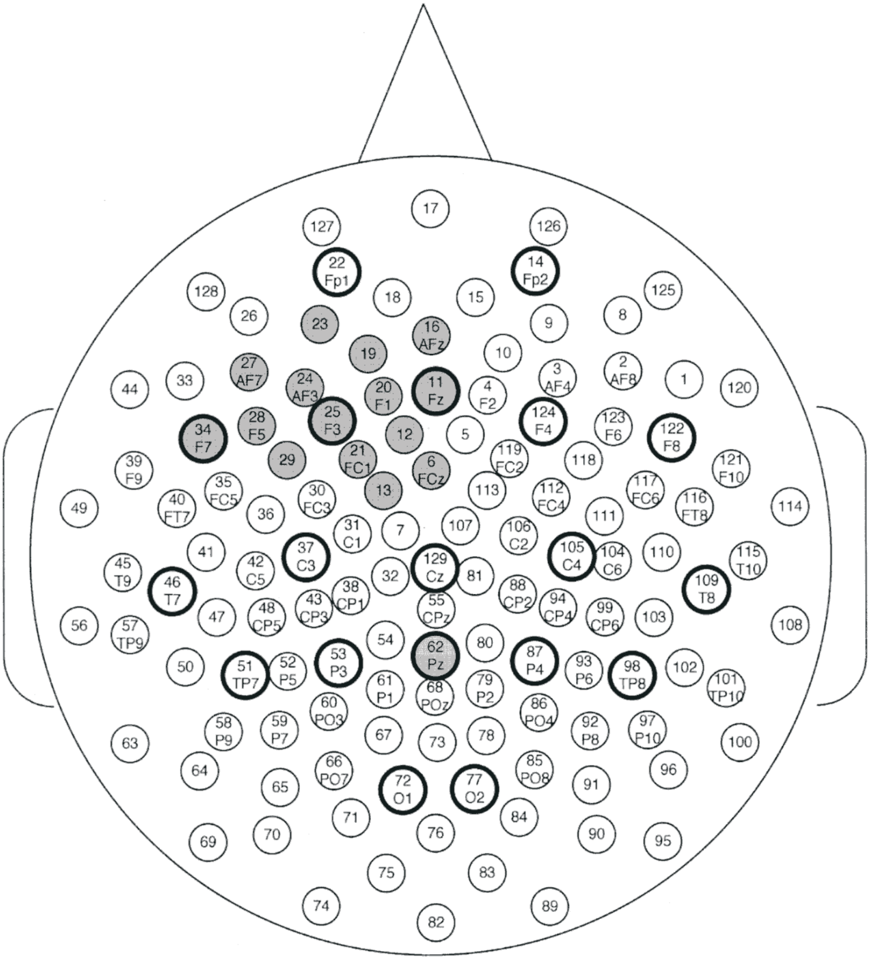


Figure 2. The 129-channel dense-sensor array displayed topographically in a top-down view of the head. Where available, the equivalent labels from the 10–10 system are shown alongside the sensor number. Selected 10–10-equivalent sensors used for the exploratory data analysis are shown by black rings. Sensors in the left fronto-central quadrant, and the Pz sensor (used in the investigation of previously identified effects) are shown by solid and lined grey shading, respectively.

t tests at each time-point were conducted in order to identify the approximate time-ranges over which the conditions differed significantly. Data were then collapsed over the identified time-range and analysed by *t* test for each of the 129 sensors in order to identify the scalp topography of the effect. Where there was a cluster of at least two adjacent sensors showing a significant effect (this restriction being imposed to reduce the number of potential sites for further analysis and to avoid investigation of spurious effects), data from the cluster were subjected to further statistical analysis. The portions of the epoch that differed significantly between conditions were defined according to the method used in our previous language-switching study (Jackson et al., 2001; based on that proposed by Rugg, Doyle, & Melan, 1993); that is, a significant difference between conditions was considered to have begun at the start of a run of at least 10 consecutive samples that each showed a significant difference between conditions (on *t* test) and ended only when followed by a run of at least 10 consecutive nonsignificant samples.

A note about presentation and description of data from the dense-sensor array is that sensor numbers used in text and figures are those applying to the 129-channel geodesic sensor nets (Electrical Geodesics, Inc.), as shown in Figure 2. Where appropriate 10–20 equivalents exist (Luu & Ferree, 2000, Technical Note), these may also be given.

Results

Behavioural data

RT and proportion error data are shown in Figure 3. A two-way ANOVA of RT data showed a significant interaction between language (L1, L2) and trial type (switch, nonswitch), $F(1, 17) = 8.31, p = .01$. The effect of switching was significant in L1 ($F = 29.0, p = .0001$; switch cost = 25 ms, 4.1% of nonswitch RT) but not in L2 ($F = 1.7, p = .2$; switch cost = 6 ms, 1.0% of nonswitch RT). In addition, whilst there was no difference between languages on switch trials ($F = 0.83, p = .4$), the benefit for L1 over L2 RTs on nonswitch trials was significant ($F = 10.0, p = .006$).

Error rates did not differ significantly across conditions ($p > .1$).

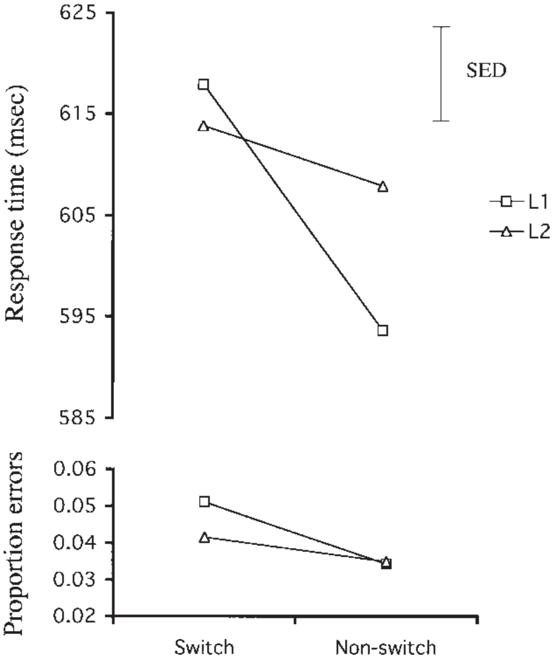


Figure 3. Mean response times (top graph) and mean proportional error scores in the parity judgement task. Error bar shows the standard error of the difference between means (*SED*).

ERP data

A. Investigation of previously identified ERP effects of language switching

A1. Fronto-central N2. Figure 4 (top panel) shows the waveforms collapsed over sensors in the left fronto-central quadrant and the topography of significant effects at 320 ms. It is clear that there is no switch-related modulation of the N2 component at 320 ms (or indeed of any part of the epoch) in the parity judgement task, as there had been in the digit-naming study (bottom panel).

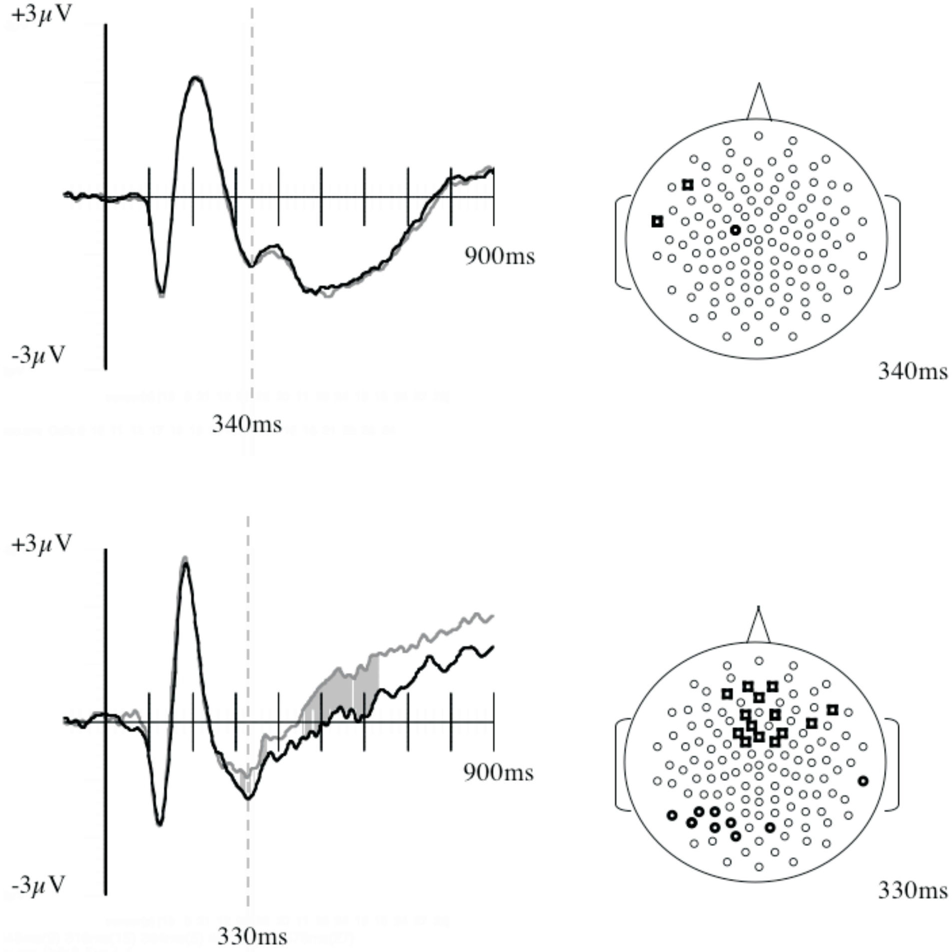


Figure 4. Grand average waveforms from the sensors in the left fronto-central quadrant in language-switch (black) and nonswitch (grey) conditions (dashed lines represent peak latency of the N2 component), and topography of sensors with significant switch-related differences at peak latency of the N2 component. Top panel: parity-judgement study. Bottom panel: digit-naming study.

A2. Parietal LPC. Figure 5 (top panel) shows the waveforms over sensor 62 (Pz) and the topography of significant effects over the time range 385–700 ms. Again, there is clearly no effect of switching, as there had been for the late positive complex and negative-going slow wave at these sites in the digit-naming study (bottom panel).

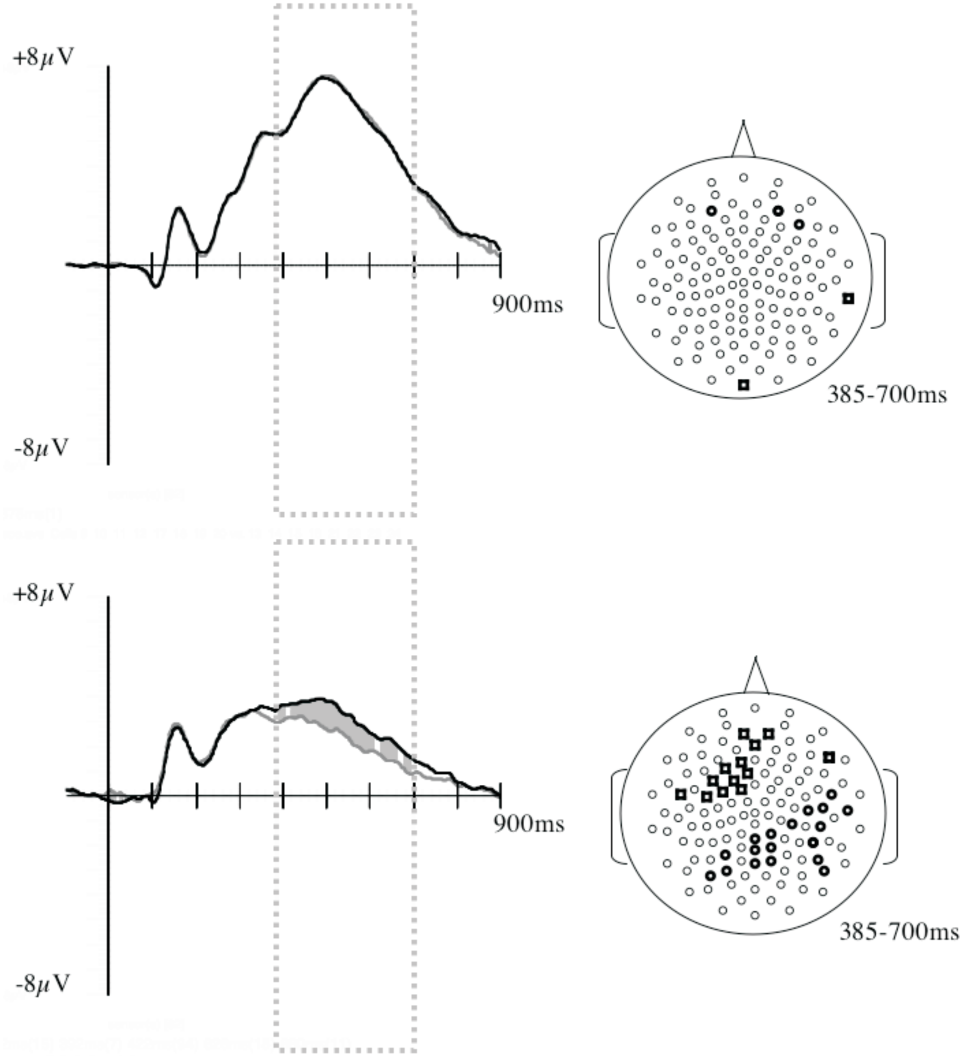


Figure 5. Grand average waveforms from sensor 62 (Pz) in language-switch (black) and nonswitch (grey) conditions (grey dotted box represents 385–700-ms time range), and topography of sensors with significant switch-related differences over the time range 385–700 ms after stimulus onset. Top panel: parity judgement study. Bottom panel: digit-naming study.

B. Exploration of data for other effects of language-switching

Data were collapsed over L1 and L2 and examined across the set of electrode sites specified from the 10–20 system. These data are shown in Figure 6. Significant effects of language switching were present early in the epoch (roughly 150–350 ms after stimulus onset) over sensors including F7, T7, TP7, and TP8 and later (roughly 400–500 ms after stimulus onset) over sensors including FP2 and F8.

B1. Early (150–350 ms) language switching effects. Data were averaged over the 150–350 ms time range and compared between switch and nonswitch conditions. The resulting topography is shown in Figure 7. Two clusters of sensors showed significant language-switch differences over this time range: a left central cluster of sensors 30 (FC3), 31 (C1), and 38 (CP1) and a right temporo-parietal cluster of sensors 98 (TP8) and 102. The switch and nonswitch waveforms from these clusters are shown in Figure 7; the left central and right

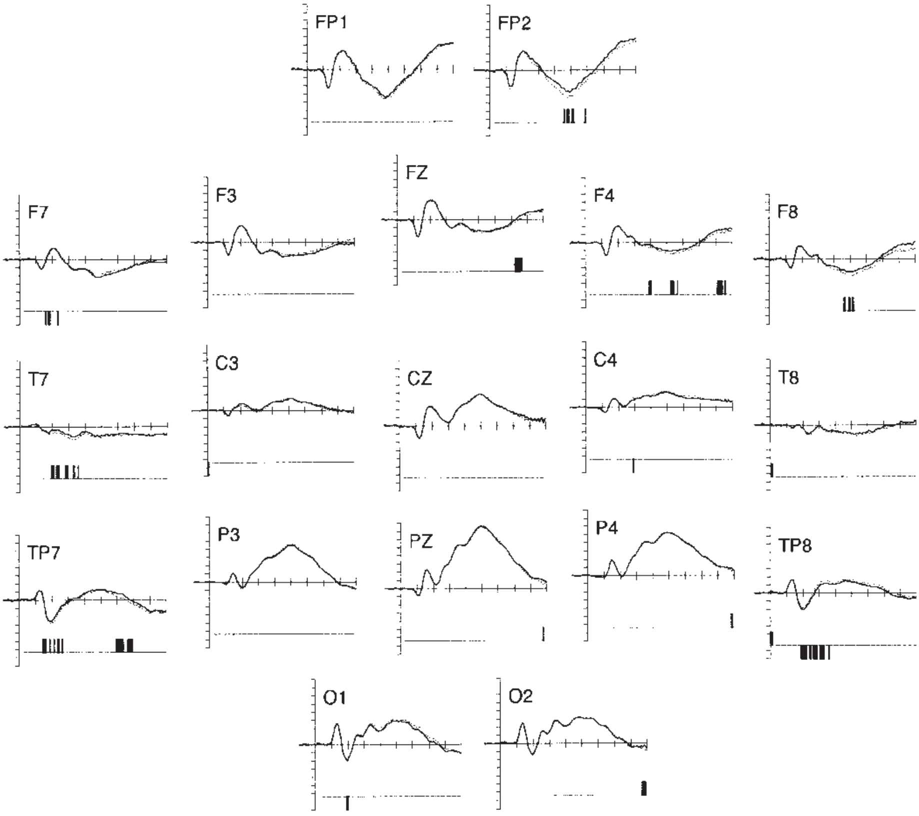


Figure 6. Waveforms for language-switch (solid lines) and language-nonswitch (dotted lines) trials, collapsed over languages, over selected 10–10-equivalent sensors. Bars beneath show time-points with significant ($p < .05$) difference between conditions: above bar = switch more positive than nonswitch; below bar = switch more negative than nonswitch.

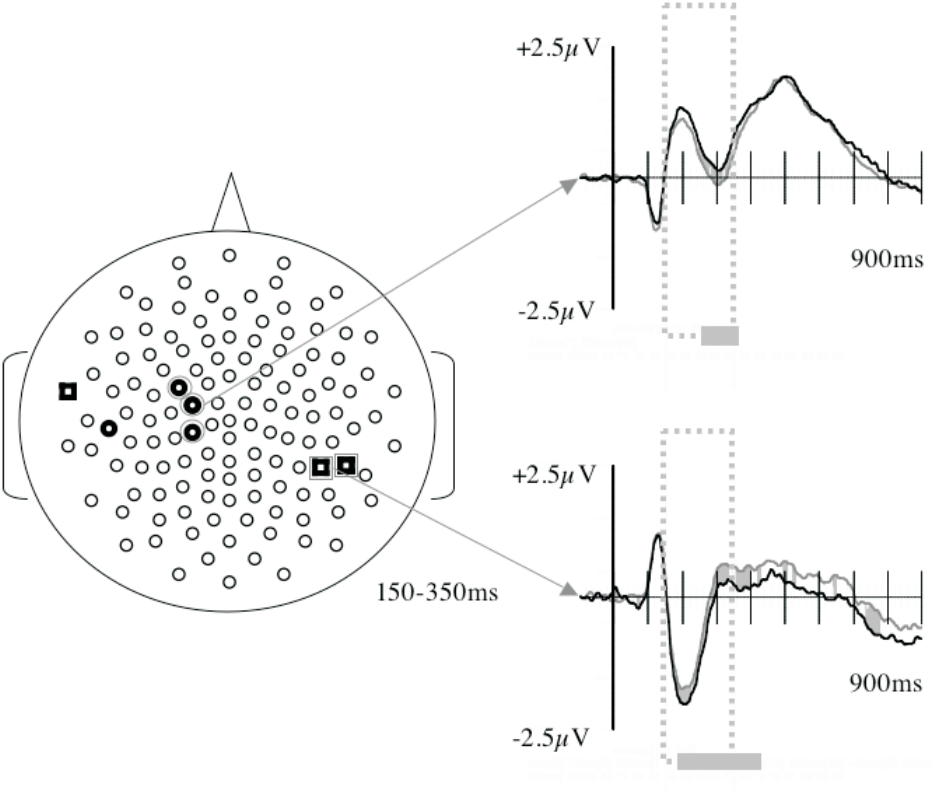
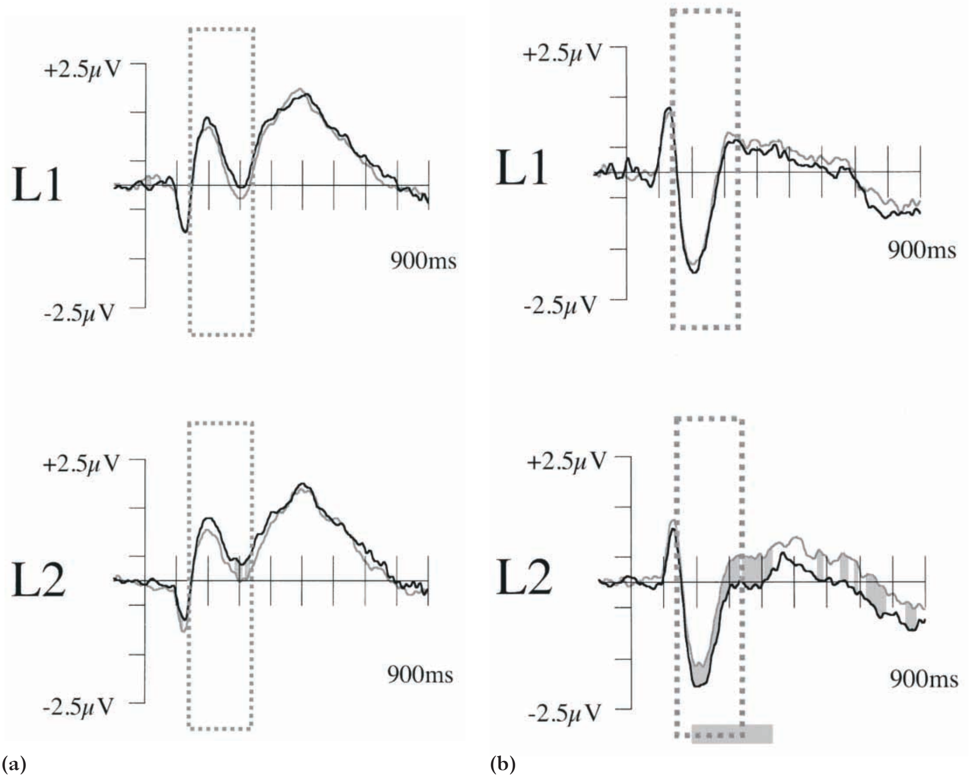


Figure 7. Early (150–350 ms) effect of language switching, collapsed across languages. Figures show topography of sensors with significant switch-related differences between 150 and 350 ms after stimulus onset (○ = switch more positive than nonswitch; ☐ = switch more negative than nonswitch) and waveforms for language-switch (black) and language-nonswitch (grey) trials over the left central (30, 31, 38; shown by grey circular border) and right temporo-parietal (98, 102; shown by grey square border) sensor clusters. Shaded areas show time-points with significant ($p < .05$) difference between conditions. Grey dotted box represents 150–350 ms time range. Grey filled box indicates time range of consecutive significance.

temporo-parietal clusters showed runs of consecutive significant values over the 252–364 ms and 184–428 ms time ranges, respectively.

The next stage was to determine whether this effect interacted with language—that is, was it specific to switching within either the first or the second language? Figure 8a shows the switch and nonswitch waveforms from the left central cluster separately for L1 (top) and L2 (bottom). In neither language did the switch effect reach significance for a sufficient number of consecutive samples, although in both cases the nonswitch waveform was more negative than the switch waveform within the 150–350 ms time range. Figure 8b shows the same comparisons but from the right temporo-parietal cluster. In L1, there were no consecutive significant samples, but in L2 the switch waveform was significantly more negative than the nonswitch waveform over the 188–432 ms time range.



(a) (b)

Figure 8. Early (150–350 ms) effect of language switching, separately for L1 (top) and L2 (bottom). (a) Left central sensor cluster (30, 31, 38); (b) right temporo-parietal (98, 102) sensor cluster. Waveforms are from language-switch (black) and language-nonswitch (grey) trials. Shaded areas show time-points with significant ($p < .05$) difference between conditions. Grey dotted box represents 150–350 ms time range. Grey filled box indicates time range of consecutive significance.

B2. Later (400–500 ms) language-switching ERP effects. Data were collapsed over the 400–500 ms time range and analysed at each sensor for differences between switch and nonswitch conditions (collapsed across languages). These data are shown in Figure 9. A single cluster of sensors showed a significant language-switching effect; this was over the right anterior frontal scalp and comprised sensors 1, 2 (AF8), and 9. The switch and nonswitch waveforms from this cluster are shown in Figure 9. There was a run of consecutive significant values in the 416–660 ms time range.

To investigate any language specificity for this effect, waveforms from the right anterior frontal electrode cluster were analysed separately for L1 and L2. These waveforms are shown in Figure 10 (L1 top; L2 bottom). In both L1 and L2, the nonswitch waveform was more negative than the switch waveform in the 400–500 ms window, but only that in L1 reached significance, doing so over the time range 416–500 ms.

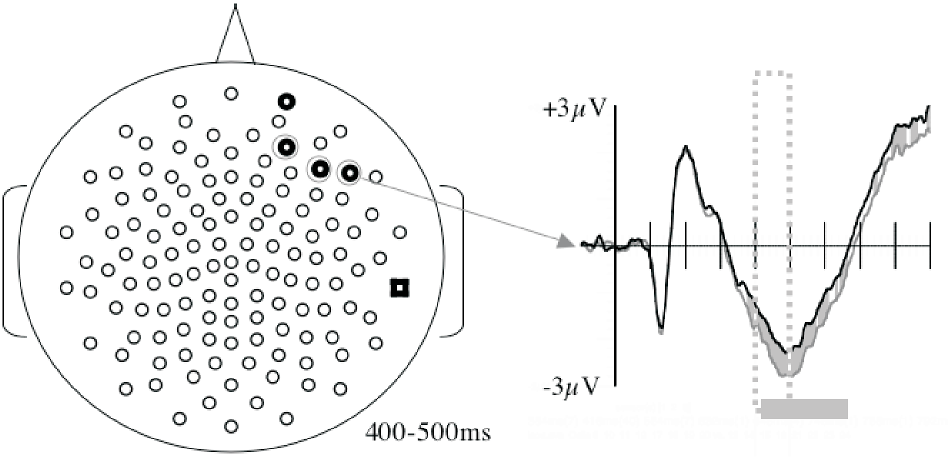


Figure 9. Later (400-500ms) effect of language switching, collapsed across languages. Figures show topography of sensors with significant switch-related differences between 400 and 500 ms after stimulus onset (○ = switch more positive than nonswitch; ☐ = switch more negative than nonswitch) and waveforms for language-switch (black) and language-nonswitch (grey) trials over the right anterior frontal (1, 2, 9) sensor clusters, which showed a significant language-switch effect over the time range 400–500 ms (collapsed across languages). Shaded areas show time-points with significant ($p < .05$) difference between conditions. Grey dotted box represents 400–500 ms time range. Grey filled box indicates time range of consecutive significance.

Discussion

In our previous study, when bilingual speakers switched back and forth predictably between speaking in their first and second languages, switching was associated with large response time costs in the order 102 ms (Jackson et al., 2001). In the current study, where bilingual speakers made a predictable receptive switch between words presented in their first and second languages, the response time costs were significant but substantially reduced (25 ms).

In the current study the “cost” of switching between languages was restricted to L1. This was not because L1 switch trials were slower than L2 switch trials; in fact they were equivalent. Rather the “cost” of switching to L1 arose from the RT advantage for remaining in the L1 during nonswitch trials. This “nonswitch benefit” was not present for L2. Similarly in our naming study we also found that switching “costs” were better described as “nonswitch benefits”. In that study participants were equally slow when switching from one language to another; however, remaining within a language resulted in RT benefits for both languages.

As predicted we found no increase in the positivity of the LPC for switch trials compared with nonswitch trials over parietal sensor sites. This finding is consistent with our previous interpretation that this effect reflects the remapping of language specific phonology-to-articulatory sets. In the current study the use of a common response set meant there was no productive differences between the two languages.

We also found that there was no increase in the N2 negativity over frontal sensor sites for L2 switch trials. This finding was unexpected. In the naming study we had assumed that the

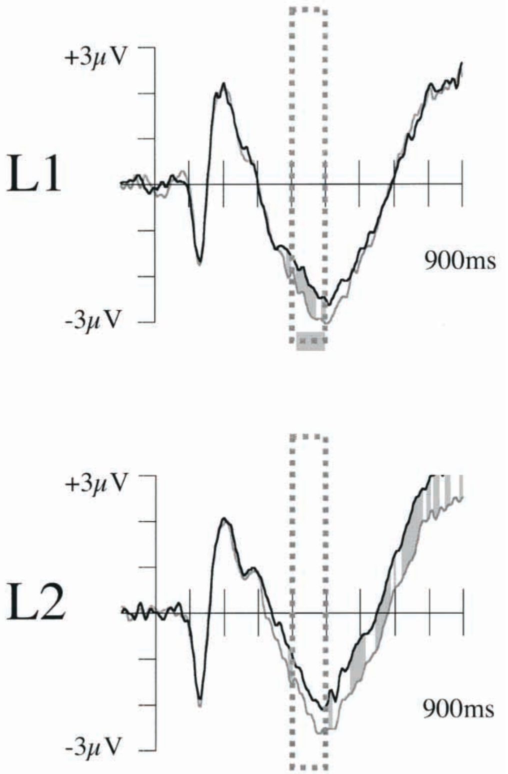


Figure 10. Later (400–500 ms) effect of language switching, separately for L1 (top) and L2 (bottom), over the right anterior frontal (1, 2, 9) sensor cluster. Waveforms are from language-switch (black) and language-nonswitch (grey) trials. Shaded areas show time-points with significant ($p < .05$) difference between conditions. Grey dotted box represents 150–350 ms time range. Grey filled box indicates time range of consecutive significance.

N2 negativity for L2 switch trials reflected suppression of the L1 response. However, we did not specify at what level this suppression might take place. Many models of the bilingual lexico-semantic system suggest that on switch trials the lexicon for the inappropriate language is deactivated (e.g., Dijkstra & Van Heuven, 1998; Grainger & Dijkstra, 1992; Green, 1998). According to these models inhibition should be required for both the naming and the parity studies. Thus in the naming study when participants are presented with a digit, the lexical item from both L1 and L2 should be activated and the inappropriate item suppressed. In the parity study, reading a word in one language should also activate the equivalent word in the other language, and once again this item would have to be suppressed. Since we did not see any frontal N2 modulation in the parity study, this suggests that the lexical selection mechanism may be non-language specific. Evidence from bilingual lexical decision (Jared & Kroll, 2001), flanker (Guttentag, Haith, Goodman, & Hauch, 1984), and Stroop tasks (Preston & Lambert, 1969) support the notion that lexical access is not restricted to one language.

If there is no competition at a representational level this raises the question of why switch costs are found for some receptive task including the current study. Recently it has been suggested that switch costs during receptive language tasks result from competition between the control structures that map the bilingual lexicon on to task-specific responses (Thomas & Allport, 2000). Within Green's Inhibitory Control model of language switching these control structures are referred to as schemas. Each language has its own schema, which compete to control output even when a common response is required for both languages (Green, 1998).

Evidence for schema level competition comes from studies that demonstrate that task and response requirements affect the magnitude of switching costs. These factors should be irrelevant if switch costs arise from competition at a representational level. Studies of lexical decision have shown that switch costs are small if subjects are asked to judge whether a letter string is a word regardless of its language (i.e., apply the single task schema "is it a word" to each item). By contrast, switch costs are large when participants judge whether an item is a word in a specific language—that is, apply one of two task schemas "is it an L1 word" versus "is it an L2 word" to each item (Thomas & Allport, 2000; von Studnitz & Green, 1997). Response costs in von Studnitz and Green's study were 17 ms in the single-schema context compared with 118 ms in the dual-schema context (von Studnitz & Green, 1997).

Evidence that the nature of the response required affects switch costs come from studies by Thomas and Allport (2000) and von Studnitiz and Green (2002). They found that language switching interacted with response type. Typically reaction times are faster when the same manual response is repeated on consecutive trials than when it is changed across trials (Pashler & Baylis, 1991; Rabbitt, 1968). However this effect is reversed when switching languages, with switch trials being slower when the same manual response is repeated than when it is changed (Thomas & Allport, 2000; von Studnitz & Green, 2002). This finding has also been reported for a non-language switching task (Rogers & Monsell, 1995).

In our study we endeavoured to remove competition between language-specific responses by using a common response for each language. However, the above studies suggest that response competition may still have been present. Our study was not designed to examine whether language switching interacts with response type, and the responding hand on each trial was randomized. Thus, within our study we did not obtain precisely equal numbers of response switch and response nonswitch trials. Furthermore, the number of response switch and nonswitch trials were not precisely equal across language switch and language nonswitch trials. Nevertheless, a post hoc examination of the RT data revealed that our data *is* in line with the results obtained in previous studies. Specifically, the difference between language switch trials and nonswitch trials was significantly greater when the manual response remained the same rather than changed, while a change of manual response resulted in a nonreliable increase in reaction time. This factor did not interact with language (L1/L2).

Unfortunately, the unbalanced numbers of trials across these comparisons makes it problematic to examine the ERPs associated with response switch versus nonswitch trials separately. However, a preliminary examination of these data suggests that a very different pattern of ERPs may be associated with these trial types. Response switch trials are associated with significant and prolonged differences between language switch and nonswitch trials over bilateral frontal sensors and right temporal parietal sensors. Response nonswitch trials are associated with differences between language switch and nonswitch trials primarily over left frontal areas. Further studies that balance language and response switching are needed to replicate these results and evaluate their implications.

Price suggests that the critical areas for semantic processing are the left inferior temporal and left posterior inferior parietal cortices. The early (250–350 ms) switch-related modulation over left central sensors in our study probably reflects semantic processing in these areas. The left central difference was not language specific and consisted of an increased positivity over the 252–364 ms time range for switch trials compared with nonswitch trials. This may reflect a priming effect for remaining within the same language. That is, access to the odd/even semantic judgement may be facilitated when the items are presented in the same language on nonswitch trials, since lexical links between number words in the same language may be stronger and/or closer than links between these items across languages (Francis, 1999). Dhond, Buckner, Dale, Marinkovic, and Halgren (2001), using MEG (magnetoencephalography), also found left temporal activity, 200–245 ms after stimulus onset during a word stem completion task, which they interpreted as activation of lexical and semantic areas. Dhond et al. found greater activity when word stems were repeated. They suggested that this might have reflected repetition rather than semantic priming.

The other early switch-related modulation effect that we observed was found over right temporo-parietal sensors. This effect was present for L2 only. It consisted of a decreased positivity for L2 switch trials compared with L2 nonswitch trials, which was present for a sustained period between 188 and 432 ms after the onset of the stimuli. Dhond et al. (2001) also found, using MEG, early activity over right posterior areas during a word stem completion task. Right hemisphere activity is frequently observed during reading tasks and may reflect the attentional processing of visual forms (Price, 1998). Finally there was a late right frontal switch effect between 416 and 660 ms after stimulus onset. This effect was only significant for L1 and consisted of an increased negativity for nonswitch trials compared with switch trials. This late effect may reflect processing of the current item or possibly preparation for the next trial. As we used a predictable trial order, increased nonswitch-related negativity might reflect preparation for the preceding switch trial. Clarifying the meaning of this switch-related modulation would require future work with both predictable and non-predictable switch sequences.

In summary, the current study demonstrates that a receptive language-switching task is associated with robust but small switching costs. The frontal switch-related activities reported in a previous productive switching study was absent in the current study, and early switch-related activity over central sensors that were not language specific were present. These findings are consistent with there being no language-specific lexical selection mechanism for receptive switching and suggest that the switching costs may arise from outside of the bilingual lexico-semantic system.

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