Is preparing for a language switch like preparing for a task switch?

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ABSTRACT

A key index of top-down control in task switching – preparation for a switch – is underexplored in language switching. The well-documented EEG "signature" of preparation for a task switch – a protracted positive-polarity modulation over the posterior scalp – has thus far not been reported in language switching, and the interpretation of previously reported effects of preparation on language switching performance is complicated by confounding factors. In an experiment using an optimised picture-naming paradigm, which addressed these confounds, the language was specified by an auditory cue on every trial and changed unpredictably. There were two key manipulations. First, the cue-stimulus interval allowed either generous (1500ms) or little (100ms) opportunity for preparation. Second, to explore the interplay between bottom-up and top-down language selection, we compared a highly transparent and familiar 'supercue' – the name of the language spoken in that language to a relatively opaque cue (short speeded-up fragment of national anthem). Preparation for a switch elicited a brain potential strongly reminiscent of the posterior switch positivity documented in task switching. As previously shown in task switching, its amplitude inversely predicted the performance 'switch cost', demonstrated by our ERP analyses contingent on RT. This overlap in the electrophysiological correlates of preparing to switch tasks and languages suggests domain-general processes for top-down selection of task-set and language for production. But, the surprisingly small language switch cost following the supercue in the short CSI suggests that rapid and (possibly automatic) bottom-up selection – not typically observed in task switching – may also occur.

Keywords: Language switching, task switching, switch cost, cognitive control, event-related potentials

Over the last decade or so, it has been intensely debated whether frequent language switching in bilinguals might enhance domain-general control mechanisms and even boost the resilience to neurodegeneration (e.g., Bialystok, Craik, & Freedman, 2007 versus Paap, Johnson & Sawi, 2015). This encourages direct examination of parallels between language switching (for a review, see Declerk & Philipp, 2015) and task switching (for reviews, see Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp, & Koch, 2010; Monsell, 2015). A change of task results in a transient 'switch cost' in performance (e.g., Rogers & Monsell, 1995) – and so does a change of language for output (e.g., Costa & Santesteban, 2004; Jackson, Swainson, Cunnington, & Jackson, 2001; Meuter & Allport, 1999). Another similarity is the 'mixing cost': performance is worse on repetition trials in mixed-language blocks, than in 'pure' (single-language) blocks (e.g., Christoffels, Firk, & Schiller, 2007) – a phenomenon also documented in task switching (e.g., Koch, Prinz & Allport, 2005). Switching from the non-dominant to the dominant language often results in a greater cost than the reverse (e.g., Meuter & Allport, 1999) – a 'paradoxical asymmetry' also found when switching between less and more practised tasks (e.g., Allport, Styles & Hsieh, 1994; Yeung & Monsell, 2003). If A, B and C are three tasks, performance on the last trial of the sequence ABA is worse than for CBA, most likely as a consequence of having to overcome the recent inhibition of the same task-set (e.g., Mayr & Keele, 2000); this n-2 repetition cost has also been found for switching among three languages (Declerck, Thoma, Koch, & Philipp, 2015; Philipp, Gade, & Koch, 2007; Philipp & Koch, 2009).

Such empirical parallels seem to suggest largely overlapping control processes that select task-set and output language (e.g., Green, 1998; Meuter & Allport, 1999). However, in at least one key aspect, cognitive control may not operate in the same way in the two domains – when the task-set or language can be selected in advance (proactively). In task-switching, increasing the preparation interval between the task cue and the imperative stimulus (up to between 0.5 and 1 s) nearly always reduces the behavioural switch cost (Kiesel et al., 2010), and the reduction tends to be substantial (often ~50% or more); it has been reported both in within- and between-participants (e.g., Elchlepp, Lavric, & Monsell, 2015) comparisons. This reduction in switch cost with preparation (the RISC effect) is widely seen as the most compelling evidence for an endogenous ('top-down'), control process of task-set reconfiguration (cf. Monsell, 2003), which can be engaged (at least in part) in advance of the stimulus. In addition to its performance index (the RISC effect) anticipatory task-set control also has an extensively documented electrophysiological correlate: a switch-induced event-related potential (ERP) observed during the late part of the preparation interval. It is typically referred to as the 'posterior/parietal positivity', due to its polarity and scalp distribution (for a review, see Karayanidis, Jamadar, Ruge, Phillips, Heathcote & Forstmann, 2010); it has been documented in different varieties of task switching paradigms (e.g., Elchlepp, Lavric, Chambers, & Verbruggen, 2016), and its magnitude predicts the reduction in switch cost within and over individuals (Elchlepp, Lavric, Mizon, & Monsell, 2012; Karayanidis, Provost, Brown, Paton & Heathcote, 2011; Kieffaber & Hetrick, 2005; Lavric, Mizon & Monsell, 2008).

In contrast, the EEG studies of language switching (e.g., Christoffels et al., 2007; Jackson et al., 2001; Verhoef, Roelofs, & Chwilla, 2009) have been concerned primarily with post-stimulus processing, and the brain-potential correlates of preparatory language selection have been underexplored. In what seems to be the only EEG study of preparation for a language switch, Verhoef, Roelofs, and Chwilla (2010) did not find during the preparation interval the above-mentioned ERP 'signature' of proactive control documented in task switching – the posterior positivity. Instead, during the preparation interval there were two ERP deflections, which were clearly different from the posterior positivity in their polarity, latency and scalp distribution. Given, the ubiquity of the posterior positivity in task switching, its absence during preparation for a language switch is a challenge for the domain-generality of proactive control processes involved in selecting task-set and language for production. This issue was noted by Verhoef and colleagues (2010), who discussed some key differences between the two domains that may lead to differences in preparatory control – the use of predominantly arbitrary responses (e.g., keypresses) in task switching versus the more "natural" (highly familiar) naming responses in language switching, the multiple stimuli-to-few responses mappings in task switching versus one-to-one S-R mappings in language switching, as well as other differences.

Unfortunately, Verhoef et al. (2010) did not manipulate the preparation interval in order to obtain a performance measure of effective preparation – the RISC effect (see above). However, a number behavioural language switching studies did. Costa and Santesteban (2004) were the first to document a RISC effect in language switching – in a between-subjects comparison. A study that followed soon was the first to examine the effects of preparation on the language switch cost within participants (Phillip et al., 2007, Experiment 1) – but found no RISC effect; there was in fact an increase in switch cost with increasing the preparation interval. Another study by Verhoef and colleagues (2009) contained a manipulation of the preparation interval – which seemed to have a differential effect on the switch cost for L1 versus L2, however no statistical tests of the RISC effect (overall, or for per language) were reported. Finally, three recent studies did report significant RISC effects (Fink & Goldrick, 2015; Declerck, Philipp, & Koch, 2013; Mosca & Clahsen, 2016).

With the exception of the study by Declerck et al. (2013)[1], where participants had to alternate between using L1 or L2 in predictable runs of 2, all the above studies used the 'cuing' paradigm to examine the effect of preparation on the language switch cost: on each trial the (otherwise unpredictable) target language was specified by a language cue. In all of these studies one cue specified each language. Thus, on a language repetition trial participants saw the same cue as on the previous trial, whereas on a language switch trial they had to encode a different cue from the cue seen on the previous trial. This likely resulted in a cue encoding benefit for repetitions but not switches – which has been previously documented in task-switching (for a review see Jost, De Baene, Koch, & Brass, 2013), and recently in language switching (Heikoop, Declerck, Los, & Koch, 2016), and shown to 'inflate' the task (or language) switch cost typically by ≥50%. Of particular relevance here is that measuring the switch cost as the difference between trials where neither the cue nor the task changes and trials where both change inflates not only the task switch cost, but also its reduction with preparation – the RISC effect – because preparation can modulate both the 'true' task switch cost, and the cue encoding benefit. This was found in several studies where an apparent RISC effect was no longer detectable when task-switch trials were compared to task repetitions where the cue changed from the preceding trial (Logan & Bundesen, 2003; Mayr & Kliegl, 2003; Monsell & Mizon, 2006, Experiment 1); see also Koch, Lawo, Fells and Vorländer (2011) for the same outcome in a 'voice switching' study where participants had to attend to

[1] This study was also different from the other studies described here (and indeed from the current study) in at least one other important respect: participants were asked to speak out word sequences they knew well (name week days in chronological order, count, or utter sequences), or were asked to learn prior to the language switching procedure.

one of two simultaneously heard speakers. Thus, to investigate the effect of preparation on the language switch cost, one needs to unconfound (or at least minimise) the effect of a language switch from effects of facilitation (priming) of cue encoding.

A further lesson from task switching is that the switch cost is reduced by both (1) increasing the cue-stimulus interval (CSI) whist keeping the response-stimulus interval (RSI) constant, and (2) increasing the RSI whist keeping the CSI constant (e.g, Meiran, 1996). Thus, to disentangle the effects of 'active' (top-down) preparation for a switch (captured by Meiran's first manipulation above) from the 'passive' dissipation of task-set carryover from the previous trial, or other effects of time elapsed since the last response (captured by Meiran's second manipulation), one must ensure that the time elapsed between the previous response and the current stimulus (RSI) remains the same whatever the preparation interval. Unfortunately, only two of the above language-cuing studies have done so – and their outcomes were contradictory: in Mosca and Clahsen (2016) preparation resulted in a RISC effect, whereas in Phillip et al. (2007) it did not.

Thus, important questions remain unanswered with regard to both the electrophysiological and behavioural performance correlates of preparation for a language switch. Does preparing for a language switch result in the same brain-potential 'signature' as preparing for a task switch? Does preparation reduce the language switch cost when one controls cue encoding and the response-stimulus interval? Here we attempted to provide some answers using a language cuing paradigm informed by the prior task switching research (see Fig. 1A and Method). To unconfound the "true" language switch effects from cue change effects, we used two cues per language and changed the language cue on every trial (e.g., Lavric et al., 2008). To ensure that potential effects of preparation are not in fact attributable to passive decay of language-set inertia (or other effects of time elapsed since the last response), we kept the RSI constant for different CSI conditions. Finally, we employed a relatively low probability of a language switch (0.33), prompted by evidence from task switching (Monsell & Mizon, 2006; Mayr, Kuhns, & Rieter, 2013; Kikumoto, Hubbard, & Mayr, 2015) that a higher probability of a switch (e.g., 0.5-0.75) reduces both the switch cost and the RISC effect, presumably because when switches are frequent participants anticipate (and prepare for) a likely switch even before the cue is presented.

The need to use two cues per language provided us with an opportunity to compare the effectiveness of different types of cue. In task-switching, non-arbitrary or semantically transparent cues result in a smaller switch cost than arbitrary cues (e.g., Arbuthnott & Woodward, 2002; Lavric et al., 2008). Furthermore, transparent verbal cues result in smaller task-switch costs than transparent picture cues (Lavric et al., 2008). Real-life switching of speech production into a language is often triggered by hearing that language spoken. We speculated that, for language preparation, the name of the language spoken in that language (e.g., "English", "Deutsch") might serve as a 'supercue' – such a cue is not merely verbal and transparent – it is also part of the lexicon of the target language, has its phonology, phonetics and prosody, and is frequently encountered by bilinguals as a language cue (and possibly used by some as an internally-generated cue). We compared the effect of this multidimensional supercue to that of an easily learned and almost arbitrary sound cue.

METHOD

Participants

Sixteen right-handed German (L1) – English (L2) bilinguals (13 females; mean age= 31.9; SD=10.2) gave informed written consent and were paid £20 for participating in the study which was approved by the local Ethics Committee (Psychology, College of Life and Environmental Sciences, University of Exeter). All the participants were living in Exeter (UK) at the time of testing, most of them were students or staff at the University of Exeter. Prior to testing, all participants completed an L2 acquisition and proficiency questionnaire (see Appendix). According to their self-report, participants started acquiring English at the age of 9.13 (SD, 3.81; range, 0-13) and spent an average 8.72 years in an English-speaking country (SD, 6.87; range, 3 months-22 years), with all but 2 participants having spent a minimum of two years in an English-speaking country. The number of years spent in a German-speaking country was 23.38 (SD, 6.77; range, 6-34). The self-assessed proficiency is summarised in Table 1. Preference for English over German was expressed by the majority of the participants for three of the four activities: listening, 68.75% of the participants; reading, 87.5%; writing, 56.25%[2]. For speaking, 50% participants expressed the preference for English over German. All participants reported using English on a daily basis for at least one of the four activities. With regard to German, 68.75% of the participants reported using it daily; 12.5% reported using it 2-3 times a week and 18.75% reported using it about once a week.

All participants had completed one to four weeks earlier a testing session using the same task and materials (but without EEG).

<insert Table 1 about here>

Stimuli, task and procedure

The stimuli were 120 black-and-white drawings of everyday objects from the International Picture Naming Project (Bates et al., 2003; http://crl.ucsd.edu/~aszekely/ipnp /1stimuli.html), which had to be named. All the written and spoken instructions were provided to all the participants in English. The naming language was specified either by a spoken word ("Deutsch" or "English") or the speeded-up beginning of the German or British national anthem (see Fig. 1A). The cue changed on every trial, alternating between word and anthem; the language changed unpredictably on 1/3 of the trials to discourage pre-cue preparation (see Introduction). The cue-stimulus interval (CSI) was varied (100ms or 1500ms) between blocks, but constant within a block. The responses and ERPs were analysed for a subset of 96 pictures (presented in 24 blocks of 48 trials). Their names were matched on mean log frequency/million (German, 0.7; English, 0.8; $t = 0.21$) using CELEX (Baayen, Piepenbrock, & van Rihn, 1993). The remaining 24 pictures were used to provide a start-up trial for each block. The 96 test stimuli were divided into two equal lists presented on alternate blocks to ensure at least 49 trials between successive presentations. Half of the participants started with one list and half with the other; half of the participants named a particular picture in L1 on its first occurrence and half in L2. Each test stimulus was presented 12 times (4 on switch trials and 8 on repeat trials).

<insert Figure 1 about here>

[2] Because the preference questionnaire item only allowed two choices – for English or for German – the % of participants who expressed a preference for German can be calculated by simply subtracting the above values from 100%.

EEG/ERPs

The EEG was recorded (sampling rate, 500Hz; bandpass, 0.016-100 Hz, reference: Cz; ground: AFz) from sixty two 10-10-configured scalp electrodes (ActiCap, BrainProducts, Munich, Germany) plus two earlobe-electrodes, then (offline) 40 Hz lowpass-filtered and re-referenced to the averaged earlobes. Because the present study focuses on preparation for a language switch and because stimulus-locked ERPs were contaminated by speech-related artifacts, our ERP analysis was confined to a 1600ms-epoch comprising the long CSI plus 100ms pre-cue interval used for baseline correction. ERPs were obtained from averaging all the relevant EEG segments, except those containing ocular, muscle, movement or other artifacts. We also excluded from both ERP and behavioral analyses the first trial of each block, errors, trials following an error, very fast (<200ms) and very slow (>3000ms) responses. Over participants, ERPs were based on 39.5 trials ±5.05 for switch conditions in the design (switch trials for each language and cue type in long CSI blocks), out of a maximum of 48 trials, and 79.97 trials ±9.76 for repeat conditions, out of a maximum of 96 trials (we remind the reader that the switch:repeat ratio was 1:2, see above). This represents 82.3% ±10.5% of trials for switches and 83.3% ±10.2% for repeats. All participants had ≥30 trials for each switch condition, except one participant who had on average 27.8 trials in switch conditions (and 57.8 an average on repeat trials).

RESULTS

Behavioural results (see Table2)

We analysed two measures of the central tendency for the naming latency – the mean and the median, as well as the error rate. The three measures were subjected to switch (2) by CSI (2) by language (2) by cue (2) ANOVAs. Responses were faster and less error prone for: repeats than switches ($F_{mean}(1,15)=45.33$, $p<0.001$[3]; $F_{med}(1,15)=38.90$, $p<0.001$; $F_{err}(1,15)=14.58$, $p=0.002$), word cue trials than anthem cue trials ($F_{mean}(1,15)=48.74$, $p<0.001$; $F_{med}(1,15)=38.03$, $p<0.001$; $F_{err}(1,15)=19.15$, $p=0.001$), and, for latencies, in the long CSI than the short CSI ($F_{mean}(1,15)=59.22$, $p<0.001$; $F_{med}(1,15)=44.01$, $p<0.001$). The advantage for the word cues relative to the anthem cues reduced in the long CSI for latencies (cue by

[3] F statistics subscripts stand for the mean RT, median RT and errors.

CSI interaction, $F_{mean}(1,15)=71.68$, $p<0.001$; $F_{med}(1,15)=52.30$, $p<0.001$). Latencies were longer for naming in L1 than in L2 ($F_{mean}(1,15)=13.29$, $p=0.002$; $F_{med}(1,15)=11.77$, $p=0.004$). The switch cost was substantially smaller for word cues than for anthem cues ($F_{mean}(1,15)=7.19$, $p=0.017$; $F_{med}(1,15)=11.13$, $p=0.005$; $F_{err}(1,15)=6.21$, $p=0.025$) and, for latencies, larger in L1 than in L2 – a 'paradoxical asymmetry' ($F_{mean}(1,15)=7.05$, $p=0.018$; $F_{med}(1,15)=6.16$, $p=0.025$).

There was no significant overall reduction in the switch cost with increasing CSI for either latencies or error rates. However, for latencies there was a significant switch by CSI by cue interaction ($F_{mean}(1,15)=23.39$, $p<0.001$; $F_{med}(1,15)=33.71$, $p<0.001$), and follow-up analyses by cue, showed that the switch cost reduced with a longer CSI for the anthem cue trials, significantly for the medians ($F_{mean}(1,15)=3.64$, $p=0.076$; $F_{med}(1,15)=8.24$, $p=0.012$), but increased with a longer CSI for the word cue trials ($F_{mean}(1,15)=24.74$, $p<0.001$; $F_{med}(1,15)=13.66$, $p=0.002$).

<insert Table 2 about here>

ERP results

Overview of ERP analyses. Although we were looking for an electrophysiological 'signature' of a known polarity and scalp distribution – the switch-related posterior positivity, we chose not to restrict our analyses temporally or spatially, allowing for the possibilities that: (1) the time-course and/or spatial distribution of the positivity may diverge somewhat from what has been reported in task-switching studies (indeed even in task-switching there is some variability in the topography and time-course of the positivity); (2) the positivity may also vary temporally or spatially for the two types of cue, and (3) notwithstanding our focus on the positivity, other switch-repeat ERP differences may emerge in language switching – and it seems important to document these.

Thus, we included in the analysis nearly the entirety of the long CSI ERP epoch (100-1500ms following cue onset[4]), averaged in 7 consecutive 200ms time-windows and all scalp electrodes – these were averaged in 12 scalp regions (each containing 4-6 electrodes) along

[4] No switch-related effects were previously reported at 0-100ms following cue onset in either task switching or language switching.

the anterior-posterior (4 levels: frontal, central, parietal and occipital) and laterality (3 levels: left, medial, right) dimensions (see Fig.1B). Our general analysis structure (tree) was to start with an 'omnibus' analysis that included the factors corresponding to all the independent variables in our design (except CSI) plus the temporal and spatial dimensions of the ERP – yielding an ANOVA with the factors: switch (2), cue (2), language (2), time-window (7), anterior-posterior (4) and laterality (3). We then followed-up statistically significant interactions that involved the factor switch – for example interactions between the factors switch and time-window were followed-up by ANOVAs for each time-window. The latter (evidently) omitted one factor (time-window), but included all the remaining factors above. Finally, we have also conducted more targeted analyses, in which we interrogated the effects revealed in the omnibus analysis and their follow-up. In one such analysis, we added an extra factor – RT distribution quantile – to examine the relation between ERP effects and performance. In another analysis, we contrasted the types of cue at specific intervals along the ERP continuum. Given the aims of the study, we only present the ANOVA effects involving the factor switch; these were Huynh-Feldt corrected for sphericity violations, but the degrees of freedom are reported uncorrected.

Does a language switch result in a posterior positivity? The omnibus ANOVA found several significant interactions involving switch: switch x time-window, $F(6,90)=11.14$, $p<0.001$, switch x time-window x anterior-posterior, $F(18,270)=4.42$, $p=0.001$, switch x time-window x laterality, $F(12,180)=6.75$, $p<0.001$, and switch x time-window x anterior-posterior x laterality, $F(36,540)=11.14$, $p<0.001$, suggesting differential effects of switch over time and across the scalp. Indeed, an inspection of the ERPs (see Fig. 2A&B) revealed a switch-induced positivity over the posterior scalp in the 300-900ms range, followed by a fronto-central switch-induced negativity at ~1100-1500ms after cue onset. Follow-up ANOVAs conducted for each time-window with factors switch (2), language (2), cue (2), anterior-posterior (4) and laterality (2) revealed significant main effects of switch both for the positivity (300-500ms, $F(1,15)=10.83$, $p=0.005$; 500-700ms, $F(1,15)=4.9$, $p=0.043$) and for the negativity (1100-1300ms, $F(1,15)=4.8$, $p=0.043$; 1300-1500ms, $F(1,15)=4.68$, $p=0.047$). In each of these time-windows switch also interacted significantly with anterior-posterior and/or laterality – reflecting the observation that the positivity was numerically maximal in the posterior regions and the negativity was maximal in the medial anterior-central regions (see Fig. 2B). In the interest of brevity, we do not report the details on these interactions. However, we did want to ascertain that the significant main effect of switch (above) in the two time-windows in the positivity range (300-500ms and 500-700ms) is also present when only the two posterior regions (parietal and occipital) are included in the analysis. ANOVAs conducted for each of these time-windows (with the same factors as above, but only 2 levels of factor anterior-posterior) revealed main effects of switch for both time-windows, $F(1,15)=11.27$, $p=0.004$; $F(1,15)=12.33$, $p=0.003$, chronologically – thus confirming that a language switch elicited a robust and sustained *posterior* positivity.

<insert Figure 2 about here>

Does the language-switch positivity predict performance? In task-switching the magnitude of the posterior positivity has been shown to predict effective preparation: in ERP analyses contingent on RT (Karayanidis et al., 2011; Lavric et al., 2008) the positivity is substantial on trials with fast responses (and a small switch cost) and reduced (or more variable, or delayed) on trials with slow responses (and a large switch cost). To ascertain whether this is also true for the language switch-induced positivity observed here, we split-half-analysed the ERPs based on naming latency distributions[5] and contrasted the ERP switch positivity for the half of the trials with the shortest naming latencies (where the switch cost was 42ms) to the switch positivity for the remaining half of the trials (where the switch cost was 97ms).

We therefore submitted the two time-windows during which the switch positivity was statistically significant (300-700ms, see above) to an ANOVA with the extra factor "fast/slow"; the other factors were switch (2), cue (2), time-window (2), anterior-posterior (4)

[5] To ensure that in the ERP analysis based on RT distributions the 'fast' vs. 'slow' contrast was not confounded by other factors (e.g., more word cue trials among trials with fast responses), the RT median split was first done by the smallest cell of the design (e.g., switch L1 word cue) and then some cells were averaged as appropriate (e.g., average of all switch cells for the fast end of the distribution). An analysis with smaller quantiles was not feasible given the available number of ERP epochs per quantile.

and laterality (3)[6]. This analysis found reliable switch x anterior-posterior, $F(3,45)=5.73$, $p=0.008$, and switch x laterality, $F(2,30)=3.42$, $p=0.046$, interactions, and most importantly, a significant switch x fast/slow x time-window interaction, $F(1,15)=5.61$, $p=0.032$. Follow-up analyses by time-window (including the same factors except time-window) revealed a significant switch by fast/slow by laterality interaction at 300-500ms, $F(2,30)=3.64$, $p=0.038$. ANOVAs for each laterality, including factors fast/slow (2), switch (2), cue (2), and anterior-posterior (4), revealed a reliable switch x fast/slow interaction for the right laterality, $F(1,15)=5.22$, $p=0.037$, suggesting that on the right side of the scalp the positivity was larger for the fast-response trials than for the slow-response trials; the analyses for the left and medial regions found only a non-significant trend for the medial region, $F(1,15)=3.31$, $p=0.089$. To ascertain that the significant switch by fast/slow interaction over the right scalp reflected (at least in part) the modulation specifically of the *posterior* positivity, we ran an ANOVA restricted to the two right-posterior regions (parietal right and occipital, right see Fig 1B), with factors fast/slow (2), switch (2), cue (2), and anterior-posterior (2); the critical switch by fast/slow interaction was significant, $F(1,15)=7.65$, $p=0.014$. These analyses confirmed that over the right posterior scalp, the magnitude of the switch positivity was inversely predictive of the magnitude of the performance switch cost (see Fig. 2C).

The same analysis as above [ANOVA with factors fast/slow (2), switch (2), cue (2), time-window (2), anterior-posterior (4) and laterality (3)] was also conducted for the time-windows where the omnibus ANOVA (above) had found significant switch-induced negativity (1100-1300ms and 1300-1500ms). There were no significant interactions involving the factor fast/slow, and, hence, no evidence that the late switch-induced negativity was predictive of effective preparation.

Is the switch positivity modulated by cue type? The much smaller switch cost for word than anthem cues in the short CSI suggests a much earlier onset of control processes involved in language selection on word cue trials. One might therefore expect an earlier onset of the posterior positivity following word cues than following anthem cues. The inspection of ERPs

[6] Simply adding a further factor (fast/slow) to the analysis would have resulted in an inadmissibly low number of ERP epochs per cell. Because in the preceding ERP analysis switch did not interact with language, the factor language was removed from the analysis based on RT distributions.

suggests this might indeed be the case (see Fig. 2D&E): the positivity on word cue trials appears to emerge and/or reach its maximum earlier than on anthem cue trials. To capture this difference, we examined the time-window where the overall positivity (across cue types, see Fig. 2B) only started to emerge (300-500ms) and the time-window where the still discernible positivity was dissipating (700-900ms) – we reasoned that this would be more informative than analysing the time range where the switch-induced positivity was maximal and thus likely robust for both cues. This ANOVA (which included the same factors as the omnibus ANOVA, but with only two levels for time-window) found a significant switch x cue x time-window interaction, $F(1,15)=6.77$, $p=0.02$[7]. Analyses by time-window by cue (with factors switch language, anterior-posterior and laterality) revealed for the word cue a significant main effect of switch for the 300-500ms time-window, $F(1,15)=17.34$, $p=0.001$, but no significant effects involving switch in the 700-900ms time-window. Conversely, for the anthem cue, there were no switch effects at 300-500ms, but a significant switch x anterior-posterior interaction at 700-900ms, $F(3,45)=11.04$, $p<0.001$. That this interaction really did reflect a reliable switch-induced *posterior* positivity was confirmed in the follow-up ANOVAs for each anterior-posterior region (with factors switch, language, cue and laterality) by a reliable main effect of switch only in the occipital region, $F(1,15)=6.07$, $p=0.026$.

DISCUSSION

Cuing the language in which an object was to be named, we looked for and found, during the cue-stimulus interval on a language switch trial, a brain potential hitherto identified as an important electrophysiological correlate of top-down control during preparation for a task-switch (cf., Karayanidis et al. 2010; Lavric et al., 2008), but previously thought to be absent in association with preparation for a language switch (Verhoef et al., 2010). It bore the hallmarks of the posterior positivity reported in task-switching: positive polarity, posterior parieto-occipital scalp distribution, onset at ~300-500ms following the cue onset, protracted time-course extending for >200ms. Furthermore, partitioning the ERPs based on fast versus slow

[7] Switch x time-window also interacted (in tandem) with anterior-posterior, $F(3,45)=7.13$, $p=0.004$, laterality, $F(2,30)=8.51$, $p=0.001$, and with anterior-posterior and laterality combined, $F(6,90)=3.62$, $p=0.004$. There was also a significant 4-way interactions between switch, cue, time-window and laterality, $F(2,30)=3.56$, $p=0.041$.

responses (as a proxy for trial to trial variation in preparation efficacy) showed that, like the posterior positivity elicited by a task switch, it predicted performance: it was larger on fast-response trials (for which the small switch cost indicate successful preparatory language selection) than on slow-response trials (for which the large switch cost suggest ineffective preparatory language selection). On switch trials the posterior positivity was followed by a protracted fronto-central negativity, whose amplitude was not as clearly related to performance. Late switch-related negativities with similar onset, duration and scalp distribution have been previously reported in some task-switching studies, particularly those using long (>1 sec) preparation intervals (e.g., Astle, Jackson, & Swainson, 2008; Tieges, Snel, Kok, Plat, & Ridderinkhof, 2007), and may reflect efforts to maintain task- or language-set after preparation.

We conclude that preparation for a language switch and for a task switch result in similar ERP effects and, when effective, are reflected by the same electrophysiological signature: the posterior ERP positivity. Our outcomes are consistent with the commonality reported in the fMRI activations associated with task switching and language switching (De Baene, Duyck, Brass, & Carreiras, 2015), and suggest overlap in control processes for selection of task-set and language for production. Whether (any of) these fMRI activations are related to the posterior ERP positivity may be determined in the future by acquiring the ERP and fMRI data concurrently (e.g., Bregadze & Lavric, 2006). How does one reconcile these findings with the substantial differences between the two domains – changing tasks typically requires a shift of attention from one perceptual attribute to another (e.g. from shape to color, or one type of character to another, or one location to another), whereas no shifts of attention are ever required during a language switch; the characteristics (and number) of stimulus-response mappings are also rather different in the two domains (cf. Verhoef et al., 2010, see Introduction). It would seem reasonable, therefore, to assume that both domains involve the (early) selection of some abstract representation of the relevant task-set ('task goal', Goschke, 2000) or language ('language task schema', Green, 1998) – and that this may the locus of the overlap.

However, one key aspect of our findings is unusual vis-a-vis the task-switching literature. For the anthem cues, a reduction in switch costs in the naming latencies with increasing CSI was observed, though the magnitude of this RISC effect was not as robust (and only significant for the medians) as in previous studies that did not control for effects of cue encoding (Costa & Santesteban, 2004; Fink & Goldrick, 2015; Mosca & Clahsen, 2016). In contrast, when language was ‘supercued’ by the word “English” or “Deutsch” spoken by a native speaker, we observed only a small switch cost of 30-40ms when CSI=100ms and no further benefit of preparation; indeed, the switch cost actually increased at the longer CSI. Such overlearned and multidimensional supercues may have no parallel in task-switching experiments – where even with transparent verbal cues the tasks tend to be novel, and habitual cue-task associations are established only during the experiment. We suggest that the linguistic supercue has two effects: (1) it very rapidly (and possibly automatically) activates its language-set, and (2) it is also more rapidly and less variably interpreted than the arbitrary cue as requiring a voluntary/endogenous change of language-set. The first effect seems to be transient – as suggested by the increase of the RT switch cost for the supercues from the short to the long CSI. The second effect, which likely persists beyond the automatic activation, is indicated by the ERP switch-induced positivity – it peaks earlier and more clearly for the supercues, in the range 300-600ms – perhaps soon enough to reconfigure the language-set when lexicalisation is required even when the CSI is short.

Thus, our analyses of performance and brain potentials as a function of cue type suggest both a voluntary preparation process similar to that seen in task switching, and more rapid and possibly automatic set-shifting elicited by hearing the language spoken (or by seeing it in print, cf. Peeters, Runnqvist, Bertrand, and Grainger, 2014). The latter is less commonly encountered in task switching, yet is likely to be at least as important as deliberate intention in day-to-day bilingual language selection for production. This observation adds to the growing literature on circumstances that can make language switches relatively effortless (cf., Kleinman & Gollan, 2016). Which of the multiple dimensions of the supercue accounts for its effect (phonetics, phonology, lexicality, semantics, familiarity, associative history, prosody) should be subject to future investigations.

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Table 1. Self-reported fluency in English.

	listening	speaking	reading	writing
mean	9.44	9.00	9.38	8.75
SD	0.73	0.89	0.72	1.06
range	8-10	7-10	8-10	7-10

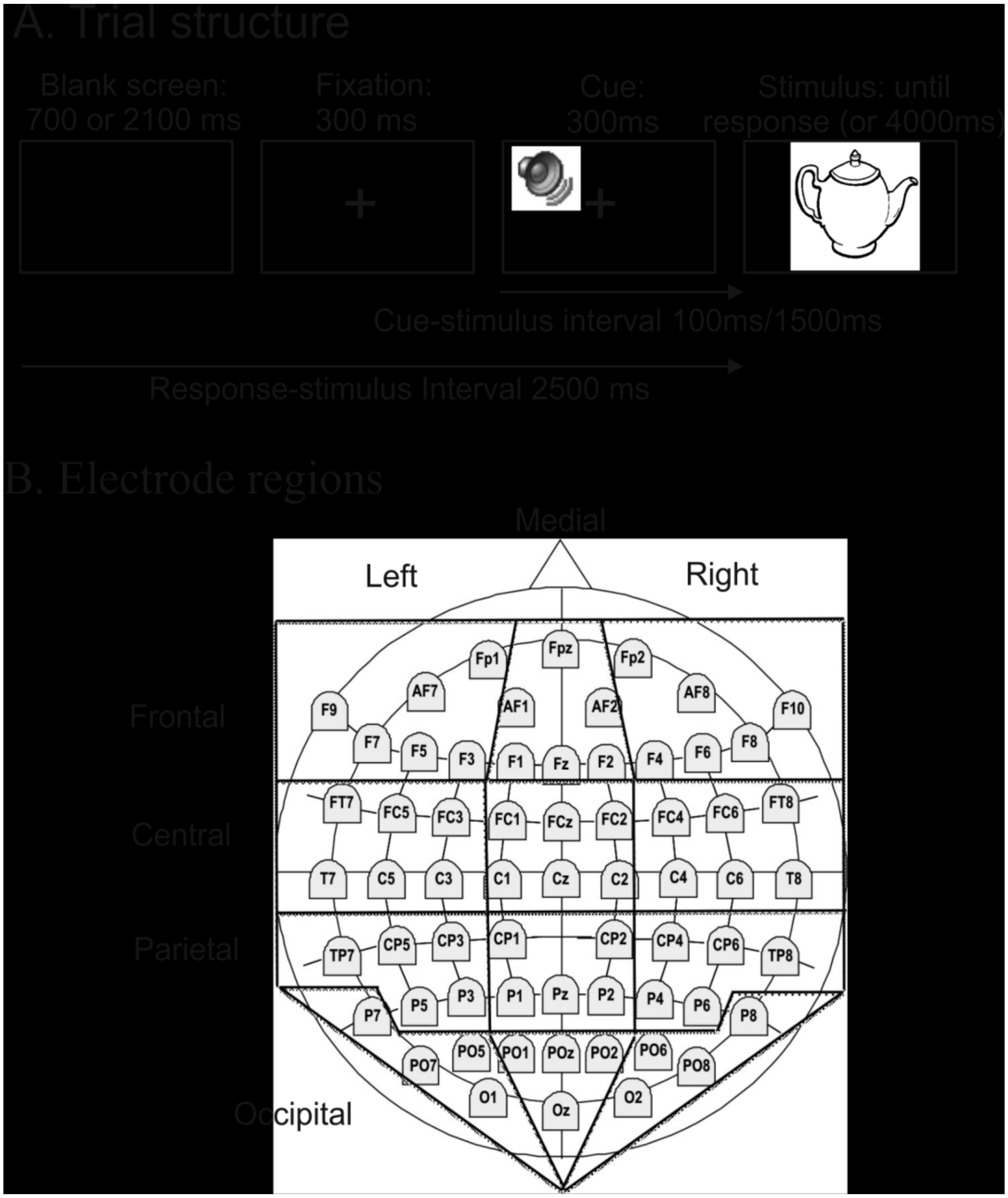
Table 2. Naming latencies and error rates.

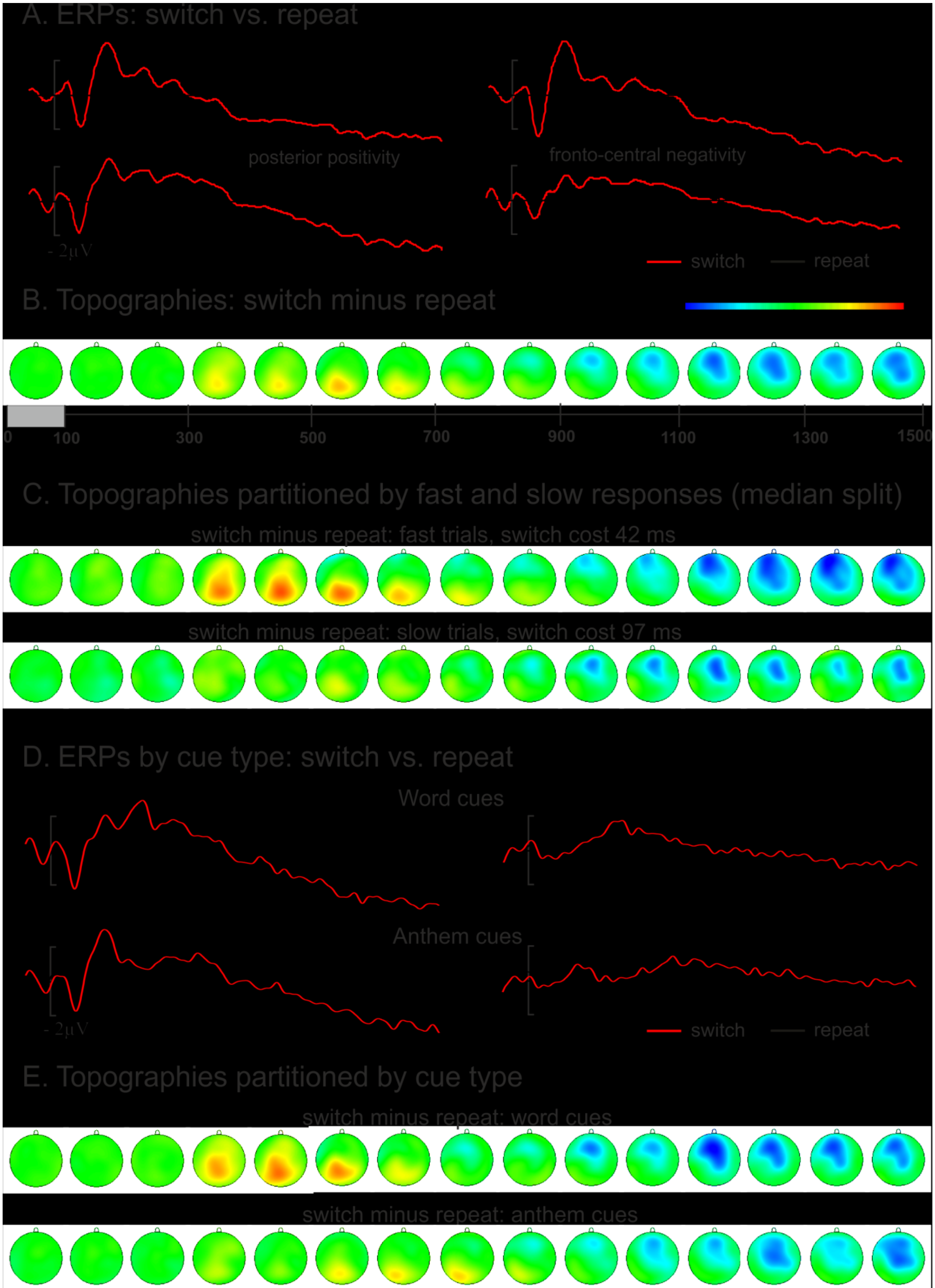
Factor	Mean RT (ms)	Median RT (ms)	Mean Error rate (%)
Switch	switch, 997	switch, 929	switch, 3.2
	repeat, 928	repeat, 852	repeat, 1.1
	switch cost, 69	switch cost, 77	switch cost, 2.1
CSI	short CSI, 1011	short CSI, 938	short CSI, 2.0
	long CSI, 914	long CSI, 842	long CSI, 2.4
Cue	word, 910	word, 845	word, 1.4
	anthem, 1015	anthem, 936	anthem, 3.0
Language	L1, 981	L1, 909	L1, 2.5
	L2, 944	L2, 872	L2, 1.8
L1	switch, 1025	switch, 956	switch, 5.1
	repeat, 938	repeat, 861	repeat, 2.6
	switch cost, 87	switch cost, 95	switch cost, 2.5
L2	switch, 969	switch, 902	switch, 4.5
	repeat, 918	repeat, 842	repeat, 2.2
	switch cost, 51	switch cost, 60	switch cost, 2.3
Word cue	switch, 936	switch, 876	switch, 7.7
	repeat, 883	repeat, 815	repeat, 1.9
	switch cost, 53	switch cost, 61	switch cost, 5.8
Anthem cue	switch, 1058	switch, 983	switch, 4.5
	repeat, 973	repeat, 888	repeat, 1.5
	switch cost, 85	switch cost, 95	switch cost, 3
Word sw. cost	short CSI, 31	short CSI, 39	short CSI, 0.8
	long CSI, 75	long CSI, 82	long CSI, 1.6
Anthem sw. cost	short CSI, 98	short CSI, 117	short CSI, 3.03
	long CSI, 70	long CSI, 72	long CSI, 3.09

FIGURE CAPTIONS

Figure 1. **A.** The present language-cuing paradigm: an auditory language cue preceded the stimulus at a cue-stimulus interval (CSI) manipulated independently of the response-stimulus interval, thus matching the CSIs for possible effects of language 'inertia' (cf. Meiran, 1996). **B.** Scalp regions that resulted from averaging over electrodes along the dimensions *anterior-posterior* (4 levels) and *laterality* (3 levels).

Figure 2. **A.** ERPs by switch vs. repeat in a representative subset of midline electrodes for the long CSI; time '0' here and in the lower panels represents the onset of the language cue. **B.** Topographic difference maps (scalp distribution of the switch-repeat difference) averaged every 100ms; 200ms time-windows used for statistical analysis are shown on the horizontal axis – the greyed-out interval was not analysed (see footnote 4). **C.** Switch-repeat difference maps by RT quantile (scale as in panel B). **D.** ERPs by cue and switch/repeat in a midline electrode (Pz) and a left-lateral electrode (P5) from the parietal region. **E.** Switch-repeat difference maps by cue (scale as in panel B).


A. Trial structure
Blank screen: 700 or 2100 ms
Fixation: 300 ms
Cue: 300ms
Stimulus: until response (or 4000ms)
Cue-stimulus interval 100ms/1500ms
Response-stimulus Interval 2500 ms
B. Electrode regions
Medial
Left
Right
Frontal
Central
Parietal
Occipital


A. ERPs: switch vs. repeat
posterior positivity
fronto-central negativity
- 2µV
switch
repeat
B. Topographies: switch minus repeat
0
100
300
500
700
900
1100
1300
1500
C. Topographies partitioned by fast and slow responses (median split)
switch minus repeat: fast trials, switch cost 42 ms
switch minus repeat: slow trials, switch cost 97 ms
D. ERPs by cue type: switch vs. repeat
Word cues
Anthem cues
- 2µV
switch
repeat
E. Topographies partitioned by cue type
switch minus repeat: word cues
switch minus repeat: anthem cues

APPENDIX

Second Language Experience Questionnaire

I am investigating how bilingual speakers process different languages. It is important that I know how much experience you have had with each of your languages. Please answer each of the following questions carefully. For some, you can write your answer directly after the question (click once in the grey box and start typing), for multiple choice questions use your mouse to click in the box next to the relevant answer.

1. What is your name?

2. What is your age?

- ☐ 17 – 20
- ☐ 21 – 24
- ☐ 25 – 30
- ☐ 31 – 34
- ☐ 35 – 40
- ☐ 40 +

3. How old were you when you started to learn English?

4. How many years have you lived in countries where German/English is the main language that is spoken?

   English speaking countries years
   German speaking countries years

5. Please rate your current fluency in German for each of these skills from one to ten; 1 being not fluent, 10 being very fluent, (please only tick one box per line)

	Not Fluent									
	1	2	3	4	5	6	7	8	9	10
Listening	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Speaking	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Reading	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Writing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

6. At the moment, how much do you use each language (in any way – speaking, writing, listening or reading? Please tick one box per language)

	German	English
Every Day	☐	☐
Two or three times a week	☐	☐
Once a week	☐	☐
Once a month	☐	☐
Less often than once a month	☐	☐

7. Which do you prefer to use for each of the following activities?

	German	English
Listening	☐	☐
Speaking	☐	☐
Reading	☐	☐
Writing	☐	☐

8. Please list all of the languages that you speak, starting with the language you know the best to the one you know the least.