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The role of proactive control on subcomponents of language control: Evidence from trilinguals

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ABSTRACT

Language control in bilingual individuals has been the source of thorough study in the last decade. However, the characterization of the subcomponents of this cognitive process remains shallow. In this experiment we tested Chinese, English, and Japanese trilinguals who completed a modified language-switching task. Participants named pictures in one of three conditions: Repeat language, Switch-away from a language (target language undetermined) and Switch-to a particular language (target language determined). Brain activity was recorded by electroencephalogram (EEG) and general proactive control ability was measured independently by the AX-Continuous Performance Test (AX-CPT). Switch-to and Switch-away processes elicited distinct neural signatures. Both at the cue and stimulus stage, Switching away elicited more negative activity at an early time window (N2); and less positive activity at the later time window (LPC). Further, at the cue stage this amplitude was negatively correlated with the proactive control index. These results show that the different subcomponents of cued-switching are dissociable and that there is a direct relation between the online signatures elicited by some of these processes and the general proactive control abilities of individuals.

1. Introduction

Individuals who can speak two or more languages have the remarkable ability to switch swiftly and accurately between them (e.g., Kleinman & Gollan, 2016; Poulisse & Bongaerts, 1994; Prior & Gollan, 2011). When language switching is determined by external constraints, this process is hypothesized to be mediated by what is frequently labeled as language control. Accumulating evidence suggests that language control is in fact a subdomain of general cognitive control, as its neural underpinnings overlap both spatially and temporally with those substrates involved during tasks that tap into cognitive control (e.g., conflict monitoring, response selection and response inhibition; Abutalebi et al., 2008; Blanco-Elorrieta & Pylkkänen, 2016; 2017; Blanco-Elorrieta, Emmorey, & Pylkkänen, 2018; Branzi, Della Rosa, Canini, Costa, & Abutalebi, 2015; Crinion et al., 2006; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Rodriguez-Fornells, Rotte, Heinze, Nösselt, & Münte, 2002; Wang, Xue, Chen, Xue, & Dong, 2007).

The literature on language switching while following external cues is rich, and this work has elicited some convergent results. The majority of this research has asked bilingual individuals to name a picture or a number in one or another language as prompted by a cue displayed on the screen (Blanco-Elorrieta & Pylkkänen, 2016; Calabria, Hernández, Branzi, & Costa, 2012; Calabria, Branzi, Marne, Hernández, & Costa, 2015; Costa & Santesteban, 2004; De Baene, Duyck, Brass, & Carreiras, 2015; Declerck, Koch, & Philipp, 2012; Kang et al., 2017; Macnamara, Krauthammer, & Bolgar, 1968; Meuter & Allport, 1999; Branzi et al., 2015; Philipp, Gade, & Koch, 2007). The results have been nearly unanimous in showing longer reaction times and higher error rates for trials in which participants must switch languages as compared to trials in which participants stayed in the same language. This finding has proven highly consistent, and has been replicated widely with multilingual individuals from many different linguistic backgrounds (Abutalebi et al., 2007; Abutalebi et al., 2011; Abutalebi et al., 2013; Blanco-Elorrieta & Pylkkänen, 2016; Bobb & Wodniecka, 2013; Branzi et al., 2015; De Baene et al., 2015; de Bruin, Roelofs, Dijkstra, & FitzPatrick, 2014; Kang et al., 2017; Declerck et al., 2012; Declerck & Philipp, 2015; Hervais-Adelman, Moser-Mercer, Michel, & Golestani, 2014; Li et al., 2015; Li, Liu, Pérez, & Xie, 2018; Philipp et al., 2007). Further, researchers have also frequently found that the cost of switching into the L1 is bigger than that of switching into the L2 (Costa

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& Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006; Meuter & Allport, 1999; Philipp et al., 2007; Philipp & Koch, 2009), which has been labeled the switch-cost asymmetry. Some researchers have taken this effect to index the higher effort required to release the increased inhibition applied to the dominant L1 (strong inhibition required since it is the dominant language) as compared to L2 (weak inhibition required since it is the weaker language). However, this pattern of it being harder to switch into the dominant task, is also replicated across a whole range of tasks that hold no relation to language or lexica (e.g., Allport & Wylie, 2000; Campbell, 2005; Cherkasova, Manoach, Intriligator, & Barton, 2002; Ellefson, Shapiro, & Chater, 2006; Koch, Prinz, & Allport, 2005; Leboe, Whittlesea, & Milliken, 2005; Lemaire & Lecacheur, 2010), suggesting that within lexicon inhibition may not be the source of this effect and additionally showing further parallelisms between language and non-language control.

However, how the different subcomponents of the switching process contribute to this profile of results is yet to be elucidated. A recent study tapped into the different subcomponents involved in the process of switching languages while following external demands, and dissociated the neural mechanisms recruited to disengage from the language that had been produced until that point, and the mechanisms involved in engaging in a new language (Blanco-Elorrieta et al., 2018). However, this experiment tested bimodal bilinguals (i.e., individuals who can speak and sign); whose languages do not, by definition, compete for motor output. Hence, it is unknown whether the subcomponents of language control are similarly instantiated in multilingual individuals who are fluent in two languages of the same modality (e.g., for individuals who *speak* two different languages). The current study aims to target this question, and to additionally characterize the extent to which these components overlap with non-linguistic cognitive control.

Let it be said that if one ascribes to a theory of lexical access by which within-lexicon control mechanisms are required for successful lexical selection in bilingual speakers (e.g., Green, 1998), then this question will be framed in terms of the similarities between within-lexicon language control and a lexicon-external, domain general cognitive control. However, if one's theory of lexical access is based on some selection-by-activation hypothesis (e.g., Finkbeiner, Almeida, Jansen & Caramazza, 2006; Blanco-Elorrieta & Caramazza, submitted), only certain situations such as language switching will necessitate such control, which will be placed outside the lexicon. The latter is the view the authors of this manuscript ascribe to, and hence "language control" in this manuscript will specifically refer to a definitely lexicon-external, potentially domain general, type of control.

Research addressing the different components of non-linguistic cognitive control has identified two subcomponents of proactive control: switching away from the old task schema and switching into the new task schema (Nicholson, Karayanidis, Davies, & Michie, 2006), that are parallel to the subcomponents of language switching identified by Blanco-Elorrieta et al. (2018). Nicholson et al. (2006) designed an experiment where participants alternated an alphabetic task (judging vowels or consonants), a numeric task (judging odd or even numbers) or a color task (judging warm or cold colors) following three different cues. The repeat cue indicated that participants had to repeat the task performed in the previous trial, the switch-away cue required participants to voluntarily perform one of the two other tasks, and the switch-to cue indicated participants which of the two other tasks they were required to perform. The cue-locked ERP results showed that switch-to and switch-away trials had a significant positive component compared with repeat trials, which the authors hypothesized was an index of proactive control. Further, the late positive amplitude decreased more sharply in the switch-away trials compared with switch-to trials, suggesting that task switching involves two discernable stages, and that more proactive control is required for switching away from the old task than to switch into a new task. These results, showing that two distinct operational stages can be discerned even within a single output domain (albeit in a general cognitive control task), in combination with those from Blanco-Elorrieta et al. (2018), showing that switching between two languages taps onto the same distinct stages (albeit across domains), leads a way to empirically verify whether language switching between two languages of the same domain relies on parallel dissociable stages. An affirmative answer to this question would provide fairly conclusive evidence that not only is there a tight relationship between general cognitive control and language control, but rather that they may both be one and the same mechanism of control.

Some ERP components associated with disengaging from the previous language and engaging in a new language have been identified during cue processing, prior to the start of lexical access (Karayanidis, Coltheart, Michie, & Murphy, 2003; Verhoef, Roelofs, & Chwilla, 2010). Karayanidis et al. (2003) utilized a switching task in which the cue was presented in isolation before the stimulus and recorded the ERP components associated with cue processing. A positive waveform was obtained 450–500 ms after cue onset for switch trials compared to repeat trials, revealing the onset of disengagement and engagement processes, independent of lexical access, at this time-scale. Verhoef et al. (2010) used a similar task, and found a late anterior negativity in switch trials compared to repeat trials (from 350 ms to 500 ms), and an early posterior negativity in switch compared to repeat trials in L2 trials. They interpreted the late anterior negativity to index disengaging from the non-target native language, and the early anterior negativity to reflect engaging in the target language (which requires more control than engaging in the first language by hypothesis). These experiments succeeded at isolating disengagement/engagement processes from lexical access and thus provided novel insight into the nature of the control mechanisms required to perform language switching.

Since these paradigms that have succeeded at isolating cue and stimulus stages have mostly reported effects during cue presentation, the question arises as to the extent to which these elements of control are involved or required during lexical access proper. Limited research has found effects during stimulus picture presentation (Liu, Rossi, Zhou, & Chen, 2014; Liu, Liang, Dunlap, Fan, & Chen, 2016), in contrast to the more abundant literature reviewed above, as well as more recent research (e.g., Zheng, Roelofs, Farquhar, & Lemhöfer, 2018), that has found no switch effects during stimulus presentation. Further, the paradigms utilized in the studies that did find processing costs at the stimulus stage did not provide direct measures; nor were they able to confirm that the found effects were in fact elicited by stimulus presentation and not spill over effects from the cue processing stage. Thus, the current experiment also aimed to address the extent to which stimulus-driven control is required, and if so, what the profile of this control will be.

Crucially, though, even in the paradigms in which cue and stimulus locked responses were successfully isolated, switch trials always involved both switching away from the previous language and switching into the new one. In other words, when the cue was presented and indicated a switch, participants only had one remaining language to switch to, so switching away from the previous language and switching to the new one happened simultaneously, preventing a dissociation between switching-away and switch-to processes.

A way around this simultaneousness is testing bimodal bilinguals, as reported in the magnetoencephalography (MEG) study mentioned previously (Blanco-Elorrieta et al., 2018). Participants in this study were American Sign Language - English bilinguals, which made it possible to isolate the switch-away stage (by asking participants to go from producing sign and spoken language simultaneously to single language production), and switch-to stage (when switching from producing one language to producing two). They found that switch-away, but not switch-to trials, engaged the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (dlPFC). Although the empirical literature on this topic is so far rather scarce, the studies reviewed above both in the linguistic domain (Blanco-Elorrieta et al., 2018) and in the general cognitive domain (Nicholson et al., 2006) suggest that the burden of language switching lies in the switch-away stage, while the switch-to stage seems relatively cost-free (see also Reverberi et al., 2015 for switch effects at the cue stage with fMRI). However, there is still no direct empirical evidence of this dissociation in two oral languages, given the simultaneous nature of switch-away and switch-to processes in this context.

The present study addressed this issue by recording ERPs while Chinese, English and Japanese trilinguals performed switch-away, switch-to and repeat trials between their three languages, following the paradigm by Nicholson et al. (2006) reviewed above (i.e., repeat cues instructed participants to use the same language as the previous trial; switch-to cues instructed participants the target language to switch into, and switch-away cues required participants to switch to any of the two other languages, but did not specify to which). Even though the Switch-Away condition is not the most common situation a multilingual individual will face, it is not as uncommon as it may seem at first. Often individuals from a bilingual community are embedded in a third language setting (i.e., Basque-Spanish bilinguals in the US, German-Turkish bilinguals in England) where they will mix the three languages in conversation. As soon as a Spanish or German individual arrives to the conversation though, they will have to switch away from Basque/Turkish to either of the two languages the person that just arrived understands, hence finding themselves in a switch-away context.

Prior to the experiment we employed the interference version of the AX-CPT designed by Braver et al. (2001), which is widely utilized to quantify participants' proactive control. Our predictions were as follows. If the ERP components in either switch-away or switch-to trials engage proactive control, these effects should significantly correlate with the proactive control measures derived from the AX-CPT. Our expectation was to particularly observe such effects in the cue-locked analysis. However, to the extent i) that the production of an utterance is a dynamic continuum that requires the successful combination of cue and stimulus retrieval, ii) that previous activation will systematically influence later stages, and iii) that participants may only reactively select a target language for Switch-away trials once the stimulus to be named was presented on the screen, we hypothesize that some part of the control effects may reemerge at the stimulus presentation stage.

2. Method

2.1. Participants

Twenty-nine trilinguals (11 male) were recruited from universities in the Beijing area. For all participants, Chinese was their first language (L1), English the second language (L2), and Japanese the third language (L3). All participants had normal or corrected-to-normal vision, and reported no neurological, reading, and speaking impairments. The study was approved by Beijing Normal University Ethics Review Board. Two participants were excluded from the analysis, one due to low naming accuracy (< 60%), and the other due to excessive EEG artifacts. The final sample reported in the analyses includes 27 (11 male) participants, aged from 18 to 24 years old ($M = 22.4 \pm 2.7$ years).

They were all non-English majors, and their College English Test Band 4 (CET-4, max point is 710) scores ranged from 500 to 600 ($M = 549 \pm 13$ points, their English level belongs to intermediate proficiency). CET-4 is the grade examination for college students of non-English majors performed by the ministry of education of China. The Japanese proficiency of the participants was above N3 (N3 was the middle level of Japanese, equivalent to CET-4), so they were all equally as proficient in Japanese and in English. Furthermore, a self-rating questionnaire was used to obtain subjective proficiency. Participants were asked to indicate how well their L1, L2 and L3 listening, speaking, reading and writing skills were. Ratings were provided using a five-point scale in which 5 indicated that L1/L2/L3 knowledge was perfect, and 1 indicated no knowledge of L1/L2/L3. Table 1 shows the self-ratings for language proficiency and age of acquisition (AoA). Two-factor within-subject ANOVA was performed on the self-rating proficiency with Language (L1, L2, L3) × Skill (listening, speaking, reading, and writing) as factors. The main effect of Language reached significance, $F(2,54) = 55.03$, $p < 0.01$, $\eta^2 = 0.61$, and pairwise comparisons showed higher proficiency in L1 than L2 and L3, while L2 did not significantly differ from L3. The main effect of Skill was also significant, $F(3,81) = 9.5$, $p < 0.01$, $\eta^2 = 0.283$. Pairwise comparisons showed that participants were best at reading and listening, followed by speaking and writing. The interaction between Language and Skill reached significance, $F(6,162) = 6.1$, $p < 0.01$, $\eta^2 = 0.20$. Pairwise comparisons showed that there was a reliable difference between the four skills in L1 (listening > speaking > reading > writing), but in L2/L3 there was no difference in proficiency between reading and listening, which were both higher in proficiency than speaking, which was reliably higher than writing (see Table 1 for a summary of participants' proficiency level). Importantly, these three languages are not similar in grapheme or pronunciation, e.g., e.g., 苹果 (L1), apple (L2), アップル (L3).

Table 1
Means (SDs) of subjective measurements of language proficiency and AOA.

Item	L1 M(SD)	L2 M(SD)	L3 M(SD)
Listening	4.85 (0.37)	3.05 (0.76)	3.55 (0.60)
Speaking	4.5 (0.51)	2.95 (0.69)	3.1 (0.91)
Reading	4.35 (0.59)	3.45 (0.60)	3.9 (0.55)
Writing	4.05 (0.60)	2.90 (0.55)	3.05 (0.99)
Age Of Acquisition (Year)	0 (0)	10.45 (1.56)	18.05 (2.1)

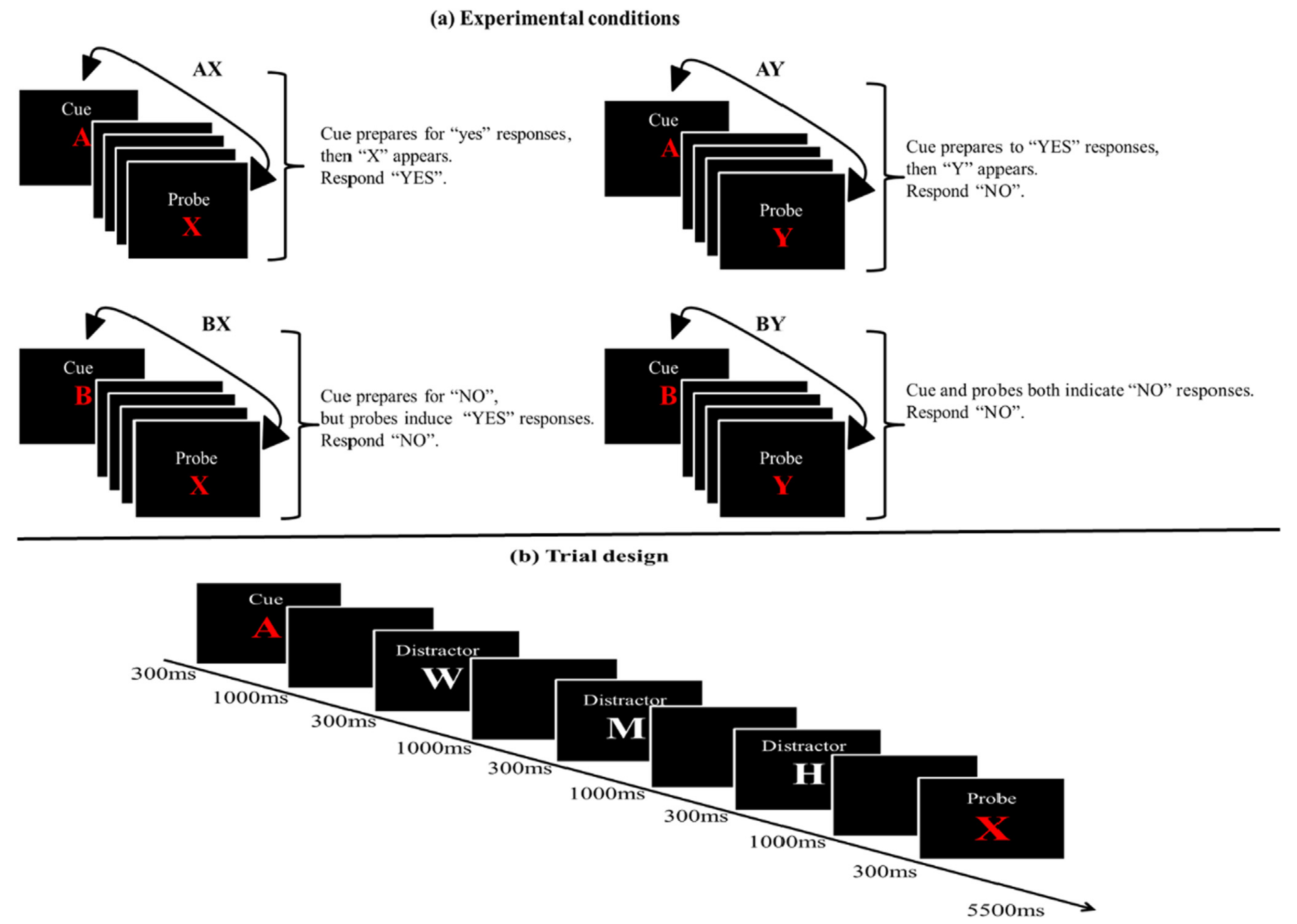
2.2. Experimental procedure

Participants were asked to complete the AX-CPT first, then do the language-switching task, and finally fill out the personal information questionnaire. The AX-CPT was presented with E-Prime 2.0 software. Stimuli were presented at the center of a 17-inch computer screen with 1024 × 768 pixel resolution.

The AX-CPT requires participants to respond "YES" to every "X" probe preceded by an "A" cue, and to respond "NO" to any probe that breaks that rule (i.e., any trial with a non "A" cue, or an "A" cue followed by any non "X" probe, see Fig. 1). The AX combination (target trials) occurs at the highest frequency (70% of trials), so participants prepare to respond "YES" after seeing an A cue. If a "Y" appears as the probe in AY trials, participants require proactive control to apply top-down the rules of the task and update their response from a "YES" (the most likely response when they saw an "A") to a "NO". In contrast, in BX and BY trials the answer is "NO" from cue presentation at the beginning of the trial and hence these trials are less taxing on cognitive control.

The AX-CPT unfolded as follows. First a red letter (cue) appeared in a black background for 300 ms, followed by three white letters (distractors). Participants were instructed to press the "N" button when the white distractors appeared. If participants did not respond at the distractor, it disappeared automatically after 300 ms. After these, another red letter appeared (probe; see Fig. 1). There was a 1000 ms blank screen between the presentation of any two letters. Participants pressed the "Y" button at the probe if the trial was AX and "N" at the probe if the trial was any other type. That is, participants pressed "N" both to continue during the distractor screens and as a "No" answer at the probe. The probe letters appearing in each trial did not repeat during the experiment. Each participant performed some practice trials prior to the beginning of the experiment. There were 4 blocks of 100 trials each in this task. AX condition had 280 trials, and AY, BX and BY conditions had 40 trials each (B represents all the cue letters except A, and Y represents all probe letters except X). Reaction time and accuracy of both distractor and probe letters were recorded. The Yes/No button order (i.e., left versus right hand) was counterbalanced for the AX-CPT.

To characterize each individual's control style, we measured the



Cue prepares for “yes” responses, then “X” appears. Respond “YES”.

Cue prepares to “YES” responses, then “Y” appears. Respond “NO”.

Cue prepares for “NO”, but probes induce “YES” responses. Respond “NO”.

Cue and probes both indicate “NO” responses. Respond “NO”.

Fig. 1. (a) Experimental conditions for the AX-CPT task. There were four different combinations between cue and probe: AX, AY, BX and BY. AX are target trials which fulfill both the A cue and the X probe requirement. AY trials fulfill the A cue requirement, biasing participants to expect the target X probe, but fail at the X probe requirement (the probe is any letter other than X). BX trials fulfill the X probe but not the A cue requirement and BY trials are control trials in which both the cue and the probe differ from the target trials. (b) Trial design of AX-CPT.

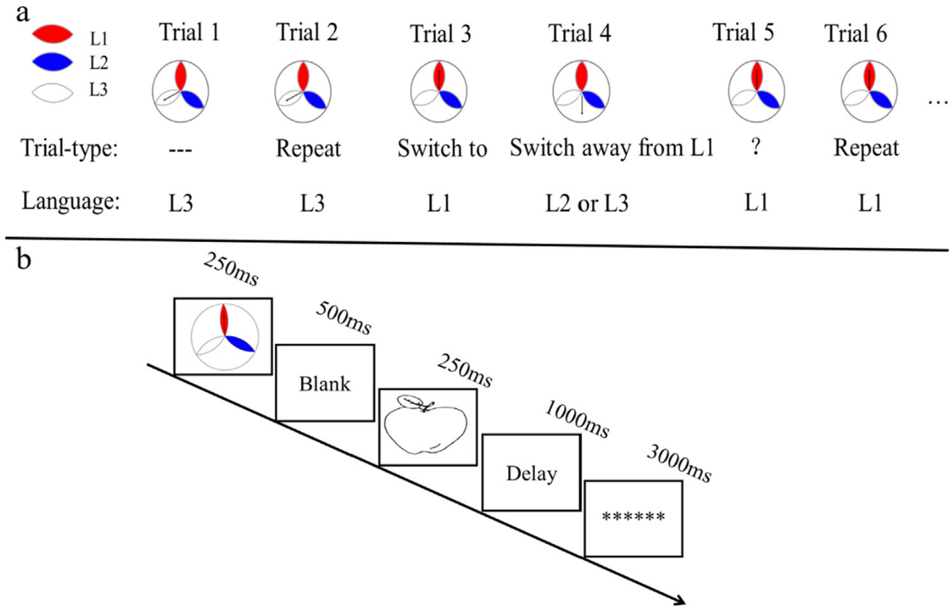


Fig. 2. (a) Experimental conditions for the language switching task. When the arrow pointed towards the same color patch in two consecutive trials (e.g., white patch in Trial 1 and Trial 2), participants named the picture in the corresponding language (white = L3) in both of those trials. In Trial 3, the arrow pointed towards a different color (red = L1), and participants switched languages to name the stimulus in the corresponding language; hence this constituted a Switch to L1 trial. In Trial 4, the arrow pointed to the space between white (L3) and blue (L2), leaving it up to the participants which of these two languages they wanted to use. This trial was a Switch-away from L1 trial, since L1 was the only language not allowed in it. Due to uncertainty about the language to be used in Trial 4, the class of Trial 5 was undefined, as were all trials following Switch-Away trials. Trial 6 was again defined based on the language of Trial 5. (b) Design and timing of trial structure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Behavioral Shift Index [BSI; (AY − BX)/(AY + BX)] of error rate and reaction times (Braver, Paxton, Locke, & Barch, 2009). A positive BSI indicates a preference for proactive control, whereas a negative BSI indicates a preference for reactive control (Paxton, Barch, Storandt, & Braver, 2006; Pérez, Hansen, & Bajo, 2018).

2.3. Language-switching task

After completing the AX-CPT, participants sat in front of a computer and familiarized themselves with the names for the pictures in L1, L2 and L3 until they got them all right, prior to performing the language-switching task. The language-switching task was presented with E-Prime 1.1.

We used 72 black-and-white line drawings (15 cm × 15 cm). These drawings were selected from the Snodgrass and Vanderwart's photo gallery standardized by Zhang and Yang (2003), and all correspond to concrete words with high frequency in Chinese, English and Japanese. Before the experiment, all participants rated their subjective familiarity with the names of the pictures in L1, L2 and L3 on a 10-point scale (1 = "very unfamiliar", 10 = "very familiar"). The analysis of variance showed that participants' familiarity with the names did not differ significantly across the three languages (F (1, 26) = 1.35, $p > 0.05$; L1 names: 8.9 ± 0.7, L2 names: 7.8 ± 1.2, L3 names: 8.0 ± 1.3). There were 8 practice words and 72 target words in each language. Cognates in any two or three languages were not included in materials (See Appendix A).

Fig. 2a gives examples of the trial design. There were 9 experimental conditions created by crossing Language (L1, L2, L3) and Trial-type (Switch-away, Switch-to, Repeat). Each condition had 64 trials, adding up to a total of 576 experimental trials. These trials were divided in 4 blocks of 144 trials, and each block included an equal amount of trials per condition (16 trials per language/condition combination per block). Note that in Switch-away trials, participants were given freedom to choose which language to switch into. For this reason, we could not classify in advance which condition the trial immediately following a Switch-away was going to belong to. A problem with response recording prevented us from post-hoc assigning which language these trials were produced in, and for this reason, we could not analyze them (3 blocks × 64 trials = 192 trials). We also excluded from further analysis the practice trials of each block (3 blocks × 8 trials = 24 trials), which left 360 trials in the final analysis (576 trials −192 trials post Switch away– 24 trials of practice). The remaining 360 trials were equally distributed across nine conditions.

Trials started with an arrow as a cue for 250 ms. Participants had to name the subsequent stimulus picture in L1, L2 or L3 depending upon whether the arrow pointed to the red, blue or white patch respectively (see Fig. 2). When the arrow pointed to a space between two colors, participants could choose to name the picture in the language represented by either color. If two consecutive trials pointed to the same color it was a repeat trial, if two consecutive trials pointed to different colors, it was a switch-to trial, and if the arrow pointed to the space between the two colors not used in the previous trial it was a switch-away trial. The result of this trial design also means that while Repeat L1 and Switch-to L1 will in fact involve responses produced in L1, trials labeled as Switch Away L1 instead reflect trials in which participants will be disengaging from L1 and answering in either L2 or L3. After the presentation of the cue, a blank screen appeared for 500 ms followed by the picture to be named (250 ms) and a blank screen 1000 ms. Afterwards, the symbol "*****" appeared, which was a signal for participants to start naming the stimulus as quickly and as accurately as possible. Participants were instructed not to respond until the symbol appeared. The symbol "*****" disappeared upon speech onset and had a 3000 ms time-out. A blank screen appeared for 1000 ms between the end of one trial and the beginning of the next. The delay between stimulus presentation and naming onset was included to avoid contamination of the EEG signal with myoelectric artifacts of language articulation (Christoffels, Firk, & Schiller, 2007; Jackson, Swainson, Cunnington, & Jackson, 2001; Martin et al., 2013). To further ensure that EEG signals were spared from oral artifacts elicited by speaking, we instructed participants to name items quietly to distort the signal as minimally as possible. However, this ended up being too quietly to be recorded by the microphone we used, so in order to preserve a clean EEG signal we unfortunately relinquished capturing meaningful reaction times from participants.

2.4. Electroencephalography acquisition and preprocessing

Electrophysiological data were recorded from 64 Ag/AgCl electrodes (NeuroScan 4.3) placed according to the extended 10–20 positioning system (Jasper, 1958). All electrodes were initially referenced to the left mastoid and later offline re-referenced to the average of the left and the right mastoid. The electro-oculogram (EOG) was recorded bipolarly; horizontal EOG was measured by placing electrodes on the outer canthus of each eye, vertical EOG by placing electrodes on the infra-orbital and the supra-orbital of the left eye. Electrode impedance was kept at 5 kΩ. Neuroscan amplifiers (synamps) were used to amplify the EEG and EOG signals. All signals were sampled between 0.1 and 100 Hz and refiltered offline with a 30 Hz, low-pass, zero-phase shift digital filter. Eye blinks were corrected in the continuous EEG data files using the algorithm developed by Semlitsch, Anderer, Schuster, and Presslich (1986) as implemented by NeuroScan software. The remaining artifacts were manually rejected. Continuous recordings were cut into epochs ranging from −200 to 800 ms relative to the presentation of the cue or of the stimulus picture. Baseline correction of cue and stimulus intervals were both performed in reference to pre-cue activity (-200 to 0 ms). Signals exceeding ± 90 μV in any given epoch were automatically discarded.

2.5. ERP analysis

Our analyses focused on two pre-defined time windows of interest. The early time-window of interest encompassed 250–400 ms, and was labeled as N2 component based on previous research on language switching (Jackson et al., 2001; Martin et al., 2013). The N2 component has been associated with conflict detection and monitoring, increased demands on cognitive control (Verhoef et al., 2010), and response selection (Gajewski, Stoerig, & Falkenstein, 2008). The second time window of interest span 400–600 ms, to target previously reported components of cognitive control (Karayanidis et al., 2003; Nicholson et al., 2006; Verhoef et al., 2010; Wu & Thierry, 2013). This later time window and accompanying topography has received different labels. Some studies found a late positive component and labeled it as P300 (e.g., Wu & Thierry, 2013), while other studies instead labelled this positive component LPC (Elke & Wiebe, 2017; Kieffaber and Hetrick, 2010; Liu et al., 2016). In the current study, since our late time window of interest starts at 400 ms, we favoured referring to this positivity as LPC. We analyzed both of these time-windows both after cue and after stimulus presentation. Spatially, we pre-defined an anterior (sensors: F1, FZ, F2, FC1, FCZ, FC2) and posterior (sensors: CP1, CPZ, CP2, P1, PZ, P2) ROIs, based on previous research suggesting that the anterior region is a more reliable source of N2 component (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Yeung, Botvinick, & Cohen, 2004), that the midline region is more sensitive to language control and that there are significant differences between the anterior and posterior brain regions (Christoffels et al., 2007; Martin et al., 2013; Jackson et al., 2001; Verhoef et al., 2010).

Data from the first two trials of each block and any trials contaminated by artifacts were removed from the analyses, which led to 9.35% of rejected trials. The average number of trials per condition was 36.32 (SD = 2.47), and the number of remaining trials did not differ across conditions as tested by a two-way repeated measures ANOVA crossing Language (L1, L2, L3) and Trial-type (Repeat, Switch-away, Switch-to).

Due to the previously mentioned response recording issue, we were unfortunately not able to exclude incorrect responses from the analysis. However, a few reasons allowed us to interpret the results despite this hiccup. Chiefly, unlike in speeded naming tasks (Zheng et al., 2018), participants were allowed plenty of time to produce the right answer, which combined with the fact that stimuli were very frequent and familiar items, made us expect very low error rates. For instance, in a similar naming task conducted by the same authors, the error rate was below 5% (Liu et al., 2016). Hence, even though including trials containing errors was not ideal, we expected the influence these may have had to diffuse over the other 95% of trials that were expected to have been completed successfully."

For statistical analyses, amplitudes were averaged across milliseconds within time-window and sensors within ROI, resulting in one data point per subject per ROI that we submitted to planned three-way repeated-measures ANOVAs crossing Language (L1, L2, L3), Trial-type (Repeat, Switch-away, Switch-to) and ROI (anterior, posterior). To further quantify the difference in magnitude of the Switch-away components for different languages, we post-hoc compared the N2 amplitude of L1, L2 and L3 Switch-away costs (Switch-away minus Repeat in each language). Last, to explore the relation between proactive control and language control, we correlated i) the BSI of error rates, and iii) the BSI of reaction times to correct trials, with the N2/LPC amplitude of Switch-away costs (Switch-away minus Repeat) and Switch-to costs (Switch-to minus Repeat). We did this for both cue-locked and stimulus-locked ERPs. When appropriate, the estimated Greenhouse-Geisser coefficient ε was used to correct for violations of the sphericity assumption (Geisser & Greenhouse, 1958). All reported p-values are based on corrected degrees of freedom with Bonferroni corrections, but to aid the reader in interpreting our statistical design, the stated degrees of freedom are uncorrected. Only comparisons significant at an alpha level of 0.05 (corrected) are reported.

3. Results

3.1. AX-CPT results

The ANOVA on the error rates of AY, BX and BY trials showed a main effect of Trial-type ($F(2,52) = 20.29$, $p < 0.001$, $\eta^2 = 0.44$). Pairwise comparisons with Bonferroni correction showed that as expected, the error rate of AY trials was higher than that of BY trials ($p < 0.001$), and that the error rate of BX trials was marginally higher than that BY trials ($p = 0.052$; see Table 2). In terms of reaction times, the main effect of Trial-type was also significant ($F(2,52) = 121.83$, $p < 0.001$, $\eta^2 = 0.82$). Pairwise comparisons with Bonferroni corrections showed that the RTs of AY trials were longer than those of BY trials ($p < 0.001$), which were in turn significantly longer than those of BX trials ($p < 0.001$).

These error rates and reaction times patterns showing higher error rates in AY trials relative to BX and BY trials is consistent both with previous literature (Braver et al., 2001; Bialystok, Craik, & Luk, 2012; Chatham, Frank, & Munakata, 2009; Morales, Gómez-Ariza, & Bajo, 2013; Morales, Yudes, Gómez-Ariza, & Bajo, 2015; Paxton et al., 2006) and with the proposal that this condition posits the highest demands on proactive control (Braver et al., 2009; Chatham et al., 2009; Morales et al., 2015; Paxton et al., 2006). Additionally, the positive BSI index indicates a dominance of proactive control (Pérez et al., 2018).

Table 2
Error rates (%) and reaction times (ms) in the AX-CPT.

	Error rates Mean (SD)	RT Mean (SD)
BY	21 (23)	442 (129)
BX	31 (23)	333 (134)
AY	39 (26)	579 (128)
AX	10 (16)	377 (166)
BSI	0.15 (0.36)	0.29 (0.15)

3.2. ERP results

The analysis of the ERP waveforms aimed to establish whether we could i) dissociate disengagement and engagement processes during language-switching in the oral domain, ii) establish which of these two underlay the increased activity associated with language switching and iii) determine how this purported cost of switching associated to general cognitive control abilities. Consistent with previous results (Blanco-Elorrieta et al., 2018; Nicholson et al., 2006), our analyses revealed that engagement and disengagement processes are in fact dissociable, and that the increased activity associated with language switching derives from disengaging processes. This was clearly observed across the board in stimulus-locked activity, and for L1 in cue-related activity. Further, the correlation analysis between ERP switching signatures and proactive control indexed by the AX-CPT showed that the mean LPC amplitude and mean LPC amplitude difference (i.e., costs) over posterior sites were negatively correlated with our index of proactive control (i.e., the BSI of AY and BX error rates). Below we describe the specific results in more detail.

1) The Switch away comparison across trial-types
   a) Cue-locked ERP results

Early time window (250–400 ms): The three-way repeated-measures ANOVA (Language (L1, L2, L3) × Trial-type (Repeat, Switch-away, Switch-to) × ROI (anterior, posterior)) revealed a main effect of Trial-type ($F(2,52) = 4.82$, $p = 0.013$, $\eta^2 = 0.16$), and three interactions between i) Language and Trial-type ($F(4,104) = 3.68$, $p = 0.014$, $\eta^2 = 0.12$), ii) Language and ROI ($F(2,52) = 5.97$, $p = 0.006$, $\eta^2 = 0.19$) and iii) Language, Trial-type and ROI ($F(4,104) = 3.71$, $p = 0.022$, $\eta^2 = 0.13$). Because of the significant interaction between language and both of the other factors, L1, L2 and L3 results were further analyzed separately. Table 3 shows the split of the reliable results performed across Trial-type and ROI for each language.

Within L1, the two-way repeated-measures ANOVA crossing Trial-type and ROI in the 250–400 ms time window showed an interaction ($F(2,52) = 12.38$, $p < 0.001$, $\eta^2 = 0.32$). Pairwise comparisons showed that Switch-away trials (-4.04 ± 3.54 μV) elicited more negative activity than Switch-to trials (-0.60 ± 4.81 μV) over anterior sensors ($p < 0.001$) (see Fig. 3, L1 trials over anterior sensors), Switch-away trials (-0.35 ± 3.47 μV) elicited more negative activity than Repeat trials (2.14 ± 3.42 μV, $p < 0.001$) and Switch-to trials (2.47 ± 3.51 μV, $p < 0.001$) over posterior sensors (see Fig. 3, L1 trials over posterior sensors; for electrode-by-electrode waveform differences see Appendix B Fig. 1). These results were not observed either in L2 or L3 trials.

Late time window (400–600 ms): This analysis revealed qualitatively parallel results with a main effect of Trial-type ($F(2,52) = 3.82$, $p = 0.028$, $\eta^2 = 0.13$), and three interactions i) between Language and Trial-type ($F(4,104) = 3.73$, $p = 0.016$, $\eta^2 = 0.13$), ii) between Language and ROI ($F(2,52) = 3.37$, $p = 0.048$, $\eta^2 = 0.12$), and iii) between Language, Trial-type and ROI ($F(4,104) = 5.12$, $p = 0.002$, $\eta^2 = 0.16$). As we did in the earlier time-window, we split the analysis

Table 3
Cue-locked ERPs results.

Time window	Language	Comparison
250–400 ms (N2)	L1	Anterior: Switch-away > Switch-to Posterior: Switch-away > Repeat Posterior: Switch-away > Switch-to
400–600 ms (LPC)	L1	Switch-to > Switch-away
	L3	Posterior: Switch-to > Repeat

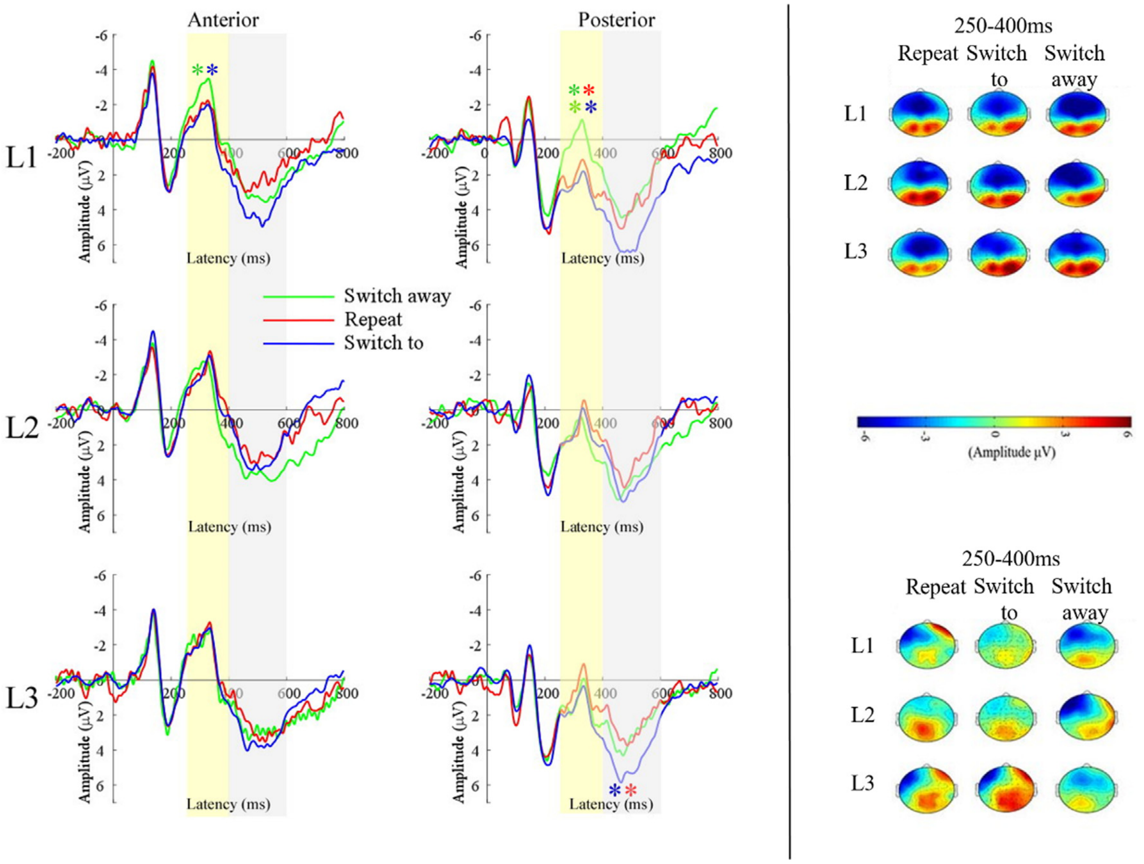


Fig. 3. Cued-locked waveforms and scalp distributions for Trial-type effect. Left panel shows grand average waveforms time-locked to the onset of the cue for the three Trial-types (Repeat, Switch away, Switch to) across languages (L1, L2, L3) in anterior and posterior sensors. The yellow and gray shading represents the early (250–400 ms) and late (400–600 ms) time windows respectively. Right panels show scalp distributions for the three levels of Trial-type (Repeat, Switch away, Switch to), across languages (L1, L2, L3) in anterior and posterior sensors, obtained from the averaged amplitude within a given time window over 64 sensors. The asterisks indicate the significant pairwise differences between the corresponding conditions. e.g., ✻✻ indicates significant difference between Switch-away (green color ✻) and Switch-to trials (blue color ✻). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

by language to unpack this three-way interaction.

The first two-way ANOVA on L1 trials (Trial-type × ROI) showed a main effect of trial ($F(2,52) = 6.43$, $p = 0.004$, $\eta^2 = 0.20$), where Switch-away trials (1.96 ± 3.83 µV, $p = 0.001$) elicited less positive activity than Switch-to trials (4.05 ± 5.34 µV). The ANOVA on L3 trials revealed an interaction between Trial-type and ROI ($F(2,52) = 3.71$, $p = 0.037$, $\eta^2 = 0.13$). Pairwise comparisons showed that Switch-to trials (3.50 ± 3.31 µV) elicited a larger LPC than Repeat trials (2.02 ± 4.72 µV) over posterior sensors ($p = 0.044$) (see Fig. 3, L3 trials over posterior sensors).

b) Stimulus-locked ERP results

Early time window (250–400 ms): The three-way repeated-measures ANOVA (Language × Trial-type × ROI) showed a main effect of Language, ($F(2, 52) = 3.62$, $p = 0.036$, $\eta^2 = 0.12$), as well as Trial-type ($F(2, 52) = 7.57$, $p = 0.003$, $\eta^2 = 0.23$). The interaction of Language × Trial-type × ROI reached significance ($F(4,104) = 10.77$, $p < 0.001$, $\eta^2 = 0.29$). As we did at the cue-locked phase, we split the analysis by language to unpack this three-way interaction (see Table 4). Table 4 shows the split of the analysis performed across Trial-type and ROI for each language.

Table 4
Summary table for stimulus-locked ERPs results.

Time window	Language	Comparison
250–400 ms (N2)	L1	Anterior: Switch-away > Repeat
		Anterior: Switch-away > Switch-to
	L2	Anterior: Switch-away > Repeat
	L3	Posterior: Switch-away > Repeat
		Posterior: Switch- away > Switch-to
400–600 ms (LPC)	L1	Anterior: Switch-away < Repeat
		Anterior: Switch- away < Switch-to
	L2	Anterior: Switch-away < Repeat
		Anterior: Switch-away < Switch-to
		Posterior: Switch-away < Repeat
		Posterior: Switch-away < Switch-to

Within L1, the two-way repeated-measures ANOVA crossing Trial-type and ROI in the 250–400 ms time window showed a main effect of Trial-type ($F(2,52) = 6.74$, $p = 0.004$, $\eta^2 = 0.21$). The interaction between Trial-type and ROI was significant ($F(2,52) = 4.44$, $p = 0.021$, $\eta^2 = 0.15$). Pairwise comparisons showed that over anterior sensors, Switch-away trials (-7.71 ± 4.00 µV) elicited more negative N2 compared with Repeat trials (-6.23 ± 3.12 µV, $p = 0.030$), and Switch-to trials (-5.33 ± 2.95 µV, $p = 0.018$) (see Fig. 4, L1 trials over anterior sensors). A similar interaction between Trial-type and ROI was also obtained within L2 ($F(2,52) = 6.11$, $p = 0.004$, $\eta^2 = 0.19$), such that Switch-away trial (-6.74 ± 3.85 µV) elicited more negative N2 compared to Repeat trials (-4.91 ± 4.20 µV) over anterior sites ($p = 0.03$) (see Fig. 4, L2 trials over anterior sensors). The ANOVA on L3 trials revealed a main effect of trial ($F(2,52) = 4.13$, $p = 0.025$, $\eta^2 = 0.14$). The interaction between Trial-type and ROI reached significance ($F(2,52) = 4.86$, $p = 0.018$, $\eta^2 = 0.16$), such that over posterior sensors, Switch-away trials (-0.97 ± 4.15 µV) elicited more negative N2 compared with Repeat trials (1.23 ± 4.61 µV, $p = 0.006$), and Switch-to

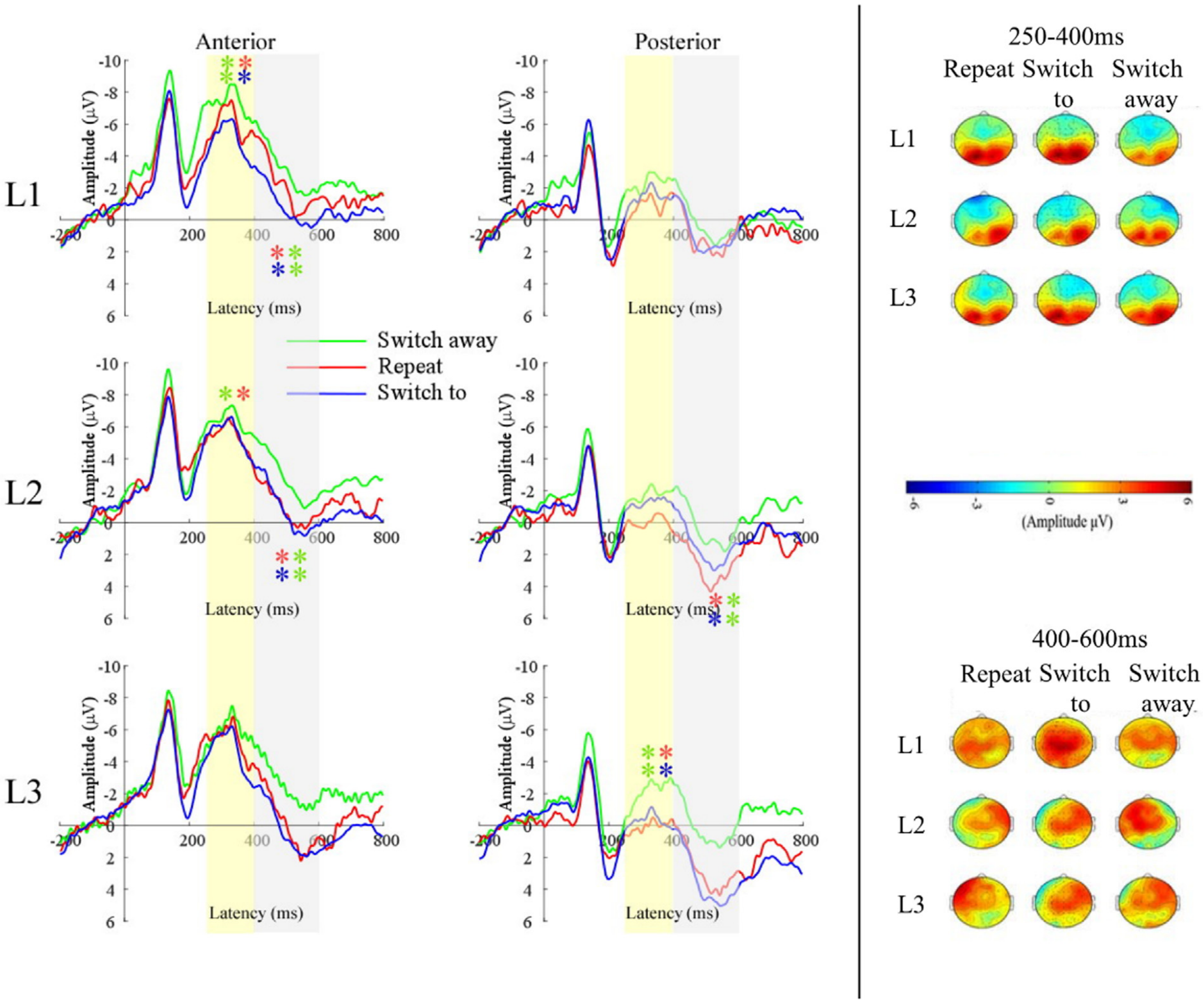


Fig. 4. Stimulus-locked waveforms and scalp distributions for Trial-type effect. Left panel shows grand average waveforms time-locked to the onset of the stimulus for the three Trial-types (Repeat, Switch away, Switch to) across languages (L1, L2, L3) in anterior and posterior sensors. The yellow and gray shading represent the early (250–400 ms) and late (400–600 ms) time windows respectively. Right panels show scalp distributions for the three levels of Trial-type (Repeat, Switch away, Switch to), across languages (L1, L2, L3) in anterior and posterior sensors, obtained from the averaged amplitude over 64 sensors. The asterisks indicate the significant pairwise differences between the corresponding conditions. e.g., ✻✻ indicates significant difference between Switch-away (green color ✻) and Switch-to trials (blue color ✻). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

trials (0.81 ± 4.15 μV, $p = 0.016$) (see Fig. 4, L3 trials over posterior sensors; for electrode-by-electrode waveform differences see Appendix B Fig. 2).

Late time-window (400–600 ms): The three-way ANOVA revealed a main effect of Language ($F(2,52) = 8.53$, $p = 0.01$, $\eta^2 = 0.25$), as well as Trial-type ($F(2.52) = 9.78$, $p = 0.01$, $\eta^2 = 0.27$). The interaction between Language, Trial-type and ROI reached significance ($F(4,104) = 4.1$, $p = 0.040$, $\eta^2 = 0.14$). We split the analysis by language to unpack this three-way interaction.

The two-way ANOVA on the L1 trials showed an interaction between Trial-type and ROI ($F(2,52) = 4.42$, $p = 0.024$, $\eta^2 = 0.15$). Over anterior sensors, Switch-away trials (-4.67 ± 3.56 μV) elicited a smaller LPC compared with Repeat trials (-1.26 ± 3.14 μV, $p = 0.048$), and Switch-to trials (-1.05 ± 3.13 μV, $p = 0.01$) (see Fig. 4, L1 trials over anterior sensors). The same ANOVA on L2 trials revealed a main effect of Trial-type ($F(2,52) = 4.18$, $p = 0.029$, $\eta^2 = 0.14$). The interaction between Trial-type and ROI was significant ($F(2,52) = 6.39$, $p = 0.003$, $\eta^2 = 0.20$), such that over anterior sensors, Switch-away trials (-2.80 ± 3.08 μV) elicited a smaller LPC compared with Repeat trials (-0.21 ± 4.57 μV, $p = 0.008$) and Switch-to trials (-1.02 ± 3.74 μV, $p = 0.035$) (see Fig. 4, L2 trials over anterior sensors); over posterior sensors, Switch-away trials (2.50 ± 4.13 μV) elicited a smaller LPC compared with Repeat trials (4.92 ± 3.83 μV, $p = 0.001$) and Switch-to trials (3.07 ± 3.29 μV, $p = 0.041$) (see Fig. 4, L2 trials over posterior sensors). The ANOVA on L3 trials revealed a main effect of Trial-type ($F(2,52) = 10.28$, $p < 0.001$, $\eta^2 = 0.28$), such that Switch-away trials (-0.89 ± 2.74 μV) elicited a smaller LPC compared with Repeat trials (1.32 ± 3.63 μV, $p = 0.018$), and Switch-to trials (1.97 ± 2.89 μV, $p < 0.001$).

In sum, at the cue-locked stage, L1 Switch-away trials elicited consistently more early negative activity than for the other conditions, and less later positive activity than Switch-to trials. At stimulus-locked stage, Switch-away trials significantly differed from both Repeat and Switch-to trials across languages, showing first a more negative N2 and later a smaller LPC.

2) The Switch-away comparison across languages

Switch-away analysis over language: The two-way repeated-measures ANOVA (Language: L1/L2/L3) × ROI (Anterior, Posterior) Switch-away costs (difference in magnitude between Switch-away and the baseline Repeat trials) showed a main effect of Language ($F(2,52) = 4.30$, $p = 0.02$, $\eta^2 = 0.14$). Pairwise comparisons showed that L1 Switch-away costs (-0.42 ± 3.29 μV) were more negative compared

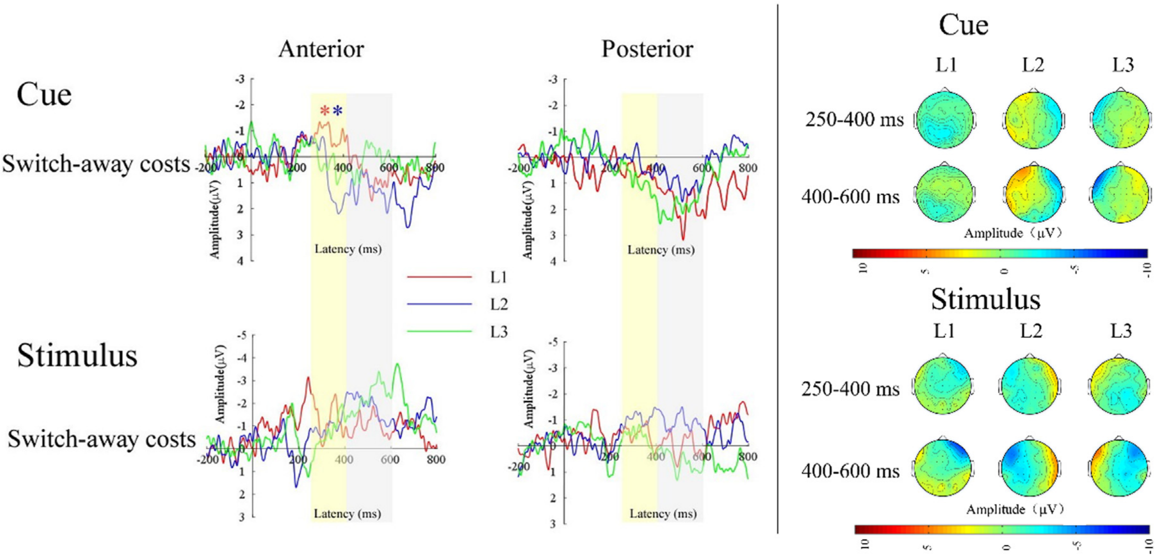


Fig. 5. Grand average of the amplitude of Switch-away costs (Switch-away – Repeat trials) time-locked to the onset of the cue for the three languages (L1, L2, L3) in anterior and posterior sensors. Top panel shows results time locked to the cue, and bottom panel results time-locked to the stimulus. The asterisks indicate the significant pairwise differences between the corresponding conditions.

with L2 Switch-away costs (0.41 ± 3.66 μV, $p = 0.013$). An interaction effect of Language × ROI (F(2,52) = 6.93, $p = 0.003$, $\eta^2 = 0.21$) was obtained, such that over anterior sensors, L1 Switch-away costs (-1.35 ± 3.47 μV) elicited more negative N2 compared with L2 Switch-away costs (1.48 ± 3.60 μV, $p = 0.001$), but there was no reliable difference in the Posterior sensors (see the upper panel in Fig. 5). The same analysis did not reveal any reliable effect at the stimulus stage.

3) Correlation analyses

This correlation analysis aimed to adjudicate the extent to which there is a direct relationship between general proactive control and amplitude of the signal during a language switch. The BSI of AY and BX error rates negatively correlated with the mean amplitude difference in cue-locked LPC while switching away from L1 and L2 (see Fig. 6a, b). These findings suggest that participants with more proactive control preference tend to have smaller LPC difference, hypothesized to index executive effort, when switching away from L1 and L2 (to see all correlations refer to Appendix C).

In brief, at the cue-locked stage, switching away from L1 trials elicited more negative N2 compared with repeat and switch to L1 trials. Importantly, the mean amplitude difference in LPC of switching away from L1 and L2 was negatively correlated with our index of proactive control. L1 and L3 Switch-to trials exhibited larger LPC compared with Repeat and Switch-away trials, but these did not correlate with the BSI of error rates. At the stimulus-locked stage, Switch-away trials elicited more negative N2 and a less positive LPC across languages. These findings suggest that language control during cued language switching includes two dissociable stages: switching away from the previous language task schema, and switching into a new one. Importantly, proactive control modulates the former stage but not the latter.

4. Discussion

The goal of the current experiment was to investigate the subcomponents of language control as a proxy to target the relationship between general executive function and language. We tested trilingual participants in an experiment designed to independently tap into two fundamental stages involved in language switching: switching away (i.e., disengaging) from the previous language, and switching into a new one (i.e., engaging in a new language). Further, we wanted to assess the extent to which activity underlying these processes, hypothesized to be mediated by cognitive control, would correlate with an independent index of proactive control (as quantified by the AX-CPT). Our results revealed a clear pattern in stimulus-locked activity: switching away elicited more negative N2 and smaller LPC activity relative to repeat and switch-to trials, and this effect held constant across all languages. The pattern of results locked to cue presentation

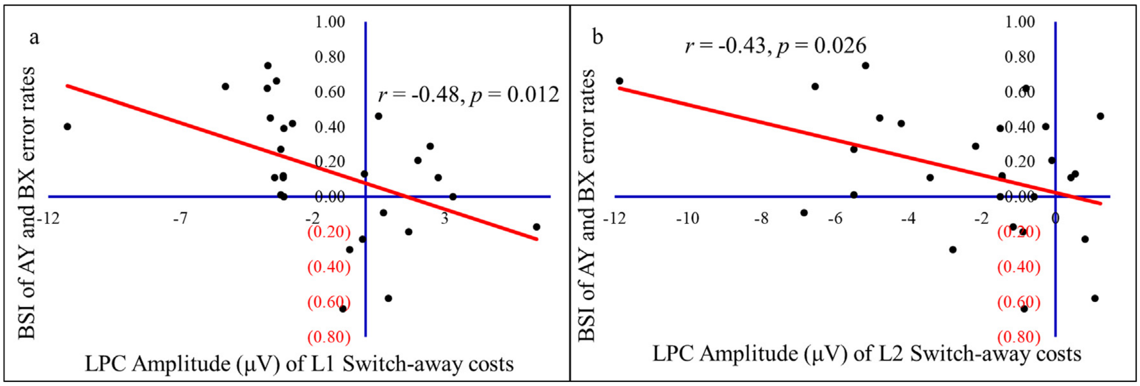


Fig. 6. Correlation analyses between indexes of general proactive control and magnitude of ERP signals. (a) The BSI of error rates negatively correlated with the mean amplitude difference in cue-locked LPC in L1 Switch-away costs over posterior sensors, and (b) L2 Switch-away costs over posterior sensors.

was somewhat less constant: switching away from L1 elicited more negative N2 than Switch-to over anterior sensors, and than Repeat trials over posterior sensors. Switch-away trials were additionally meaningfully tied to our indices of proactive control: At the LPC window, the decreased positivity of Switch-away trials over posterior sensors correlated with the BSI of error rates, both in L1 and in L2.

These findings are consistent with three arguments. First, there is a direct relation between the proactive control capacities of individuals and their success at tasks that require "language" control. Second, there are at least two dissociable subcomponents involved in language switching while following external cues: switching away from the previous language and switching into a new language. Third, consistent with previous research, switching away seems to be the driving force of switching effects. These ideas are developed as follows.

4.1. The role of proactive control on cue and stimulus phases

First we aimed to isolate control processes at the cue stage, devoid of lexical access, and we found that at this stage, there was already a dissociation between Switch-away and Switch-to trials, consistent with previous studies (Blanco-Elorrieta et al., 2018; Karayanidis et al., 2003; Verhoef et al., 2010). Further, the N2 effect and LPC effect in our study aligned closely in time and space with the two distinct ERP components Verhoef et al. (2010) identified: early switch-related negativity over posterior sites between 200 and 350 ms, and a late anteriorly distributed switch-related activity in the 350–500 ms time window both for the native language and for the third language. They proposed that the two ERP components reflect endogenous control, and the different topographies of the early and late ERP components reflect the different neuronal assembles contributing to the effects. This interpretation is additionally consistent with the Dual Mechanism Control (DMC) model, which posits that proactive control is responsible for pre-processing the target-related aspects through endogenous attention (Braver, 2012). Our results would by hypothesis also reflect proactive control associated with the process of disengagement from an old language task schema, and this interpretation is supported by the correlation between decreased positivity in LPC component with the BSI of error rates.

But why did only L1 switch-away trials show a disengagement effect in the N2 component? Since L1 is the most familiar language for unbalanced trilinguals, it would follow that it is harder to disengage from it than from the other two. Hence, in order to perform this process increased top-down attention may be required, and our results suggest that the better proactive control of the individuals (as indexed by the more positive BSI index), the easier the switching away from the L1 (as indexed by ERP negativity). Under this hypothesis, trilinguals with better proactive control would be better at updating and maintaining the goal-relevant information derived from the cue, leading to decreased amplitude of online markers of cognitive effort. Importantly, the correlation between the BSI index on error rates (i.e., a higher tendency for proactive control) and ERP components was found over posterior sensors, which have been hypothesized to pick up activity from superior parietal cortex (Braver, Reynolds, & Donaldson, 2003; Kimberg, Aguirre, & D'Esposito, 2000; Miller & Cohen, 2001; Posner & Petersen, 1990). Braver et al. (2003) found superior parietal cortex to be increasingly active in switch compared to repeat trials during a general domain task. They proposed that this region may reflect processes associated with the online reconfiguration and updating of task-set information immediately following a switch in task. Other studies also argue that this region is centrally involved in representing task-set or goal-related information or in switching attentional focus (Miller & Cohen, 2001; Posner & Petersen, 1990). In our study, it appears that participants required less effort at that later time window, if they had successfully engaged in proactive control.

During stimulus processing, switching away from all L1, L2 and L3 trials showed more negative N2 and smaller LPC compared with repeat and switch-to trials. According to previous language control studies, stimulus induced N2 reflects task inhibition and conflict resolution (Jackson et al., 2001; Martin et al., 2013). Hence the N2 would index participants' cue information retrieval to direct attention to the right language. In contrast, in the late stimulus phase, the switch-away trials triggered a smaller LPC than the other two trial types. Given the timing of the effects, it is plausible that the bulk of the cognitive work for switch-away trials was done at the cue stage, making it sufficient preparation for the late stimulus phase. Therefore, at the late stage (400–600 ms), the construction of the stimulus–response may already be completed for these trials, leading to a decrease of LPC amplitude.

4.2. The relation between executive function, language control and lexical access

The construct of executive function encompasses the organizational and self-regulatory skills required for goal-directed non-automatic behavior, including sustaining and shifting attention, inhibiting prepotent but maladaptive responses, selecting goals and holding information in mind whilst performing a task (Hughes & Graham, 2002; Norman & Shallice, 1986; Shallice & Burgess, 1991; Welsh & Pennington, 1988).

Given that external factors such as the interlocutor and the context in which bilinguals find themselves require them to engage in a number of these subprocesses in order to control their language output, researchers have long discussed a potential relationship between executive function and language control. While some researchers suggested that there is some difference between the two (e.g., bilingual individuals develop specialized mechanisms to control language: Abutalebi et al., 2008; Calabria et al., 2012); others have suggested that "language" control is instead part of general cognitive control (Craik & Bialystok, 2006; Garbin et al., 2010; Abutalebi et al., 2013; Blanco-Elorrieta & Pylkkänen, 2016).

In the current study, we found that there was a statistically significant relation between the index of proactive cognitive control as measured by the AX-CPT, and the amplitude of the ERP signatures of language control. This finding has two important theoretical implications. First, these results provide compelling evidence that there is no such thing as a language control mechanism that is purely independent of domain general cognitive control. Instead, it would seem that linguistic tasks that tap into the processes that constitute executive function exploit the mechanisms in place for controlling behavior generally. This idea is additionally supported by experiments that find overlapping underlying neural substrates for both types of control (Abutalebi et al., 2008; Blanco-Elorrieta & Pylkkänen, 2016; 2017; Blanco-Elorrieta et al., 2018; Branzi et al., 2015; Crinion et al., 2006; Hernandez et al., 2001; Rodriguez-Fornells et al., 2002; Wang et al., 2007), and by experiments that found that executive capacity of bilingual individuals was influenced by the linguistic context in which participants found themselves in; i.e., in a context in which both languages were presented and hence there was no constraint on either of them, the executive demands decreased (Blanco-Elorrieta & Pylkkänen, 2017; Wu & Thierry, 2013). Hence, while one could have previously made an elaborate argument in favor of them being independent systems that happen to overlap to a big extent, the fact that in this study their magnitudes in two different measures (ERPs and BSI indices) are correlated with each other suggests that in fact, it is more likely that there is instead one type of control that applies to both language and non-language control. From this, it follows that bilingual advantages on cognitive control, if anything, would arise from bilingual individuals engaging frequently in the type of language usage that taps into this general control network. By hypothesis, these would be the individuals that are well-versed in having to switch languages based on external cues using proactive control (for full argumentation see Blanco-Elorrieta & Pylkkänen, 2018)."

Second, and importantly, the fact that control is needed in this particular situation does not necessarily imply that fluent bilingual communication requires particular or additional control. There are two possibilities as regards to how lexical access could be achieved in bilingual individuals. One possibility is the hypothesis presented by Green and colleagues (Green, 1986; Green & Abutalebi, 2013, etc.) where control needs to occur within the lexical system for successful communication to be achieved. Specifically, a bilingual would have to control their languages through inhibition of the inappropriate lexical items in order to succeed at selecting the target elements. If we take this theory at face value, and imagine some inhibitory mechanism that is lexicon-internal, it would be difficult to imagine how such a specific control mechanism would generalize beyond linguistic tasks, and how it would correlate with general domain control. Unless one would add a Ptolemaic turn by which even though language control exists within the lexicon, it is shared by general executive control and somehow the capacities in both of these correlate by some undefined transfer system.

An alternative possibility is that the control processes assumed to mediate language production in bilinguals are in fact outside the lexical system. Under this assumption, one could argue that the networks at play are in fact not only overlapping but the same, hence readily explaining both the fact that this lexical-external device is shared with non-linguistic tasks, and setting the expectation that their capacities should be inherently associated. We believe that the current results, as well as results showing overlapping networks between control during linguistic and non-linguistic tasks support the latter of these hypothesis, and hence argue that control during language use must be a lexicon-external system. This is consistent with the model of bilingual lexical access proposed by Blanco-Elorrieta and Caramazza (submitted) where they propose a purely activation-based system for lexical selection in bilinguals, and a general domain system to resolve conflict (be it linguistic or else) outside the lexicon.

5. Conclusions

In all, the current study empirically verified that switching between languages that belong to the same domain relies on parallel dissociable stages as switching between general domain tasks (Nicholson et al., 2006) and switching between languages of different modalities (Blanco-Elorrieta et al., 2018). Further, it replicated that switching-away seems to carry the burden of the cognitive effort associated with cued-switching, and showed that there is a reliable relation between this activity and an independent index of proactive control. Our findings show that the attention and control required to perform these types of language switching tasks are not specific to the language system: operations that involve language but follow external constraints behave similarly to tasks requiring general cognitive control, providing further evidence that there may be no specific language control mechanism that is purely independent of domain-general cognitive control. These results thus call to attention to the importance of contextual cue processing during language switching, highlight how such information could be used to generate proactive expectations regarding the upcoming lexical process, and show by analogy how much of the language switching effects ascribed to language may in fact be due to the general domain cognitive task associated with the utilized paradigms.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2019.104055.

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