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Control mechanisms in voluntary versus mandatory language switching: Evidence from ERPs

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ABSTRACT

The present study measured event-related potentials (ERP) and behavioral performance to examine whether inhibitory control is involved in voluntary language switching, and if so, to explore the differences in inhibitory control between voluntary and mandatory language switching. Unbalanced Chinese-English bilinguals completed two picture naming tasks: one involving mandatory language switches and one in which participants could voluntarily switch between the two languages. Behavioral data showed significant switch costs and a reversed language dominance effect in both switching tasks. Critically, both effects were larger in mandatory compared to voluntary switching. ERP results revealed that neural switch costs during mandatory switching was significantly different than voluntary switching in both N2 and LPC amplitudes. In contrast, a significant difference in the reversed language dominance effect between both tasks was only observed in LPC amplitude. Together, these findings suggest the involvement of inhibitory control in both mandatory and voluntary language switching, but the degree of inhibition and the time-course of control processes between both tasks appear to be distinct.

1. Introduction

In their daily lives, bilinguals select and use either their first (L1) or second (L2) language, or they switch between them depending on situational needs and the individuals with whom they interact. For instance, when a bilingual speaks with someone who only knows one of their languages, they must select the appropriate target language while temporarily “suppressing” the irrelevant language. By contrast, when a bilingual speaks with someone who knows both of their languages, they can freely switch between the two languages without affecting the message conveyed. Although it has been claimed that bilinguals are able to flexibly adapt mental processes underlying language control according to various situations (Green and Abutalebi, 2013), little is still known about how bilingual language control adapts to mandatory and voluntary switching contexts. The current study aims to fill this gap by comparing the time-course of control during voluntary and mandatory switching through event-related potentials (ERPs) and behavioral performance.

1.1. Reactive and proactive control in language switching

During speech production, a bilingual's two languages are activated in parallel, creating a source of cross-linguistic interference (Starreveld et al., 2014). It has been argued that language control helps to minimize interference from the nontarget language when speaking in the target language (Green, 1998). In the literature on language switching, two types of control processes have been identified: reactive and proactive language control (Ma et al., 2016; for a review see Declerck and Koch, 2022). To measure reactive and proactive language control, language switching tasks typically are used in which participants name aloud a series of numbers or pictures in either the L1 or L2 according to an accompanying cue.

Reactive language control functions at a local (i.e., trial-by-trial) level in response to cross-language interference (Ma et al., 2016). The costs in response times (RTs) and accuracy associated with language switching are a quantitative index of reactive control (Christoffels et al., 2007; Liu et al., 2019a; Schwieter and Sunderman, 2008). Language switch costs refer to the difference in performance on repetition trials (i.e., the response language is the same as the immediately preceding trial)

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and switch trials (i.e., the response language is different from the immediately preceding trial). Previous studies have shown that switch costs depend on the level of proficiency in the L2 (Costa and Santesteban, 2004; Linck et al., 2012; Schwieter and Sunderman, 2008; Verhoef et al., 2010): Asymmetrical switch costs are typically observed in unbalanced bilinguals, such that an L1-to-L2 switch is less costly (i.e., faster and more accurate) than an L2-to-L1 switch, and symmetrical, or nearly symmetrical, switch costs are commonly found in balanced bilinguals (Liu et al., 2021; Liu et al., 2019b; Philipp et al., 2007).

Proactive language control functions at a global (i.e., non-trial-specific) level and occurs due to anticipation of cross-language interference. A typical index of proactive language control is the reversed language dominance effect in which there is poorer performance in the L1 compared to the L2 in a language switching block (Bobb and Wodniecka, 2013; Christoffels et al., 2007; Kroll et al., 2006; Liu et al., 2019a). Previous studies examining proactive language control have also analyzed mixing costs (i.e., the difference between non-switch trials in mixed blocks versus in single-language blocks) and the blocked language order effect (i.e., worse performance in single-language blocks after having completed a single-language block in another language) (Declerck, 2020).

1.2. Control mechanisms in mandatory and voluntary language switching

While both reactive and proactive control in language switching have been widely investigated, this large body of literature has mainly focused on mandatory language switching. In the mandatory language switching task, bilinguals are specifically instructed to name items in the L1 or L2 depending on a cue (e.g., national flag, colour of background screen, etc.). Numerous studies have found evidence of inhibitory control during mandatory language switching (Declerck and Philipp, 2015; Guo et al., 2011; Misra et al., 2012). One consistent finding is that language switch costs are observed in mandatory language switching tasks (Meuter and Allport, 1999). According to the inhibitory control model (ICM), language switch costs represent the (re)activation of a language that, until it had been directly called upon, was suppressed during naming in the target language (Green, 1998). Moreover, several studies have reported a reversed language dominance effect, arguing that it may arise from the constant inhibition on an L1 (Declerck and Koch, 2022). Evidence from electrophysiological studies has shown that in mandatory language switching, inhibition may occur during the language selection phase as reflected by the N2 component, as well as during the lexical selection phase as reflected by the late positive component (LPC) (Jackson et al., 2001; Liu et al., 2016).

Whether and how inhibitory control functions in voluntary language switching, on the other hand, the data have been inconsistent. While some studies have found switch costs in voluntary language switching (de Bruin et al., 2018; Gross and Kaushanskaya, 2015), others have not (Blanco-Elorrieta and Pylkkänen, 2017). The ICM proposes that the lexical selection is achieved by inhibition of the non-target language. However, the lexical accessibility account suggests that there are two processes in speech production: concept selection and lexical selection, and that the accessibility of items is a crucial factor influencing voluntary language switching (Gollan and Ferreira, 2009). Moreover, other studies have shown that items with higher frequency of use are more frequently named in the less-dominant language, demonstrating the close relationship between language selection and lexical access (Gross and Kaushanskaya, 2015).

According to the adaptive control hypothesis (ACH), language control processes adjust to meet the needs of the various language contexts bilinguals encounter (Abutalebi and Green, 2016; Green and Abutalebi, 2013). Specifically, the ACH identifies three different contexts to which language control mechanisms adapt. In single language contexts, bilinguals exclusively use one of their languages (e.g., one language at home, one language at work). In dual-language contexts, bilinguals use their two languages, but with different interlocutors. In situations of dense code-switching, bilinguals can switch between the languages freely with other speakers who also know both languages. In a study testing the ACH, de Bruin et al. (2018) compared language switching in mandatory and voluntary contexts. Although the results revealed switch costs in both mandatory and volunteer language switching, using two languages was more costly than using one (mixing cost) in mandatory switching whereas using two languages in voluntary switching was less costly (mixing benefit). These findings offer behavioral evidence that language control processes vary between mandatory and voluntary switching. However, to our knowledge, no study to date has investigated the electrophysiological differences between these two types of language switching.

1.3. The present study

The present study aimed to compare proactive and reactive language control processes during voluntary and mandatory language switching. A group of unbalanced bilinguals completed voluntary and mandatory language switching tasks in separate blocks. In the voluntary language switching task, participants could choose the language in which to name target pictures; while in the mandatory language switching task, they were required to respond in a specific language. Following de Bruin et al. (2018), both mandatory and voluntary language switching in the present study included a cue (a ‘mandatory’ cue or a ‘voluntary cue’) to minimize differences between the two tasks.

Analyzing ERPs offers the opportunity to explore the time-course of proactive and reactive control and compare them between voluntary and mandatory language switching. Based on previous ERP studies in the bilingualism literature (Jiao et al., 2020; Martin and Orgogozo, 2013; Verhoef et al., 2009), we focused on the N2 effect and LPC. The N2 component is associated with prepotent response inhibition during conflict monitoring and is closely related to reactive control (Egner and Hirsch, 2005; Folstein and Van Petten, 2008). Zhang et al. (2020) found that larger N2 amplitudes were associated with mixing costs, suggesting that the N2 component may also interact with sustained proactive control. The LPC component has been widely associated with proactive control in recent studies (Liu et al., 2020; Timmer et al., 2019).

Regarding behavioral performance, we anticipate that if inhibitory control is present in voluntary language switching, we should observe switch costs or the reversed language dominance effect. Specifically, based on previous findings (Costa and Santesteban, 2004; de Bruin et al., 2018; Jevtović et al., 2020), we expect that switch costs and the reversed language dominance effect in voluntary language switching will be smaller than in mandatory language switching. Moreover, given that both N2 and LPC reflect reactive control processing (Egner and Hirsch, 2005), we hypothesize that the electrophysiological data will reveal differences in switch costs between both language switching tasks as reflected by N2 and LPC components. While for proactive language control, we expect differences in the reversed language dominance effect between voluntary and mandatory language switching as reflected by the LPC component.

2. Method

2.1. Participants

This study was approved by the research ethics committee at Qingdao University. Thirty-four students from the same university were recruited and were offered monetary compensation for their participation. All participants provided their informed consent before taking part in the study and reported having no neurological, hearing, or reading impairments. Due to higher EEG artefacts or error rates, five participants were excluded, leaving a total of 29 participants (19 females, 10 males, mean age: 22.24 years, SD: 1.88, range: 19–25).

Prior to the language switching experiments, the participants were given a questionnaire in which they provided information about their age, language background, and level of proficiency in their two languages. All participants were Chinese L1 speakers and had no travel or learning experiences outside of China. Their mean age of acquisition (AoA) of English was 8.03 (SD = 2.41) and had taken intensive English classes in high school because English proficiency is a university entrance requirement. The participants rated their L1 and L2 language abilities (listening, speaking, reading, and writing) on the seven-point scale (Liu et al., 2022), 1 = the lowest level of proficiency, 7 = the highest level of proficiency. Paired sample *t*-tests revealed significant differences between each of the L1 and L2 abilities (see Table 1).

2.2. Design and procedure

The study uses a 2 (task: voluntary-switch, mandatory-switch) × 2 (type: switch, repeat) × 2 (language: English, Chinese) within-subjects design. Seventy-two black-and-white line drawings were selected from Zhang and Yang (2003). The participants then familiarized themselves with these pictures and their names in Chinese and English. Following this, they completed a practice session including 12 trials. These 12 pictures were not used in the formal experiment which consisted of a voluntary language switching block and a mandatory language switching block. In accordance with previous work (Kleinman and Gollan, 2016), the two experimental blocks were presented in a fixed order (i.e., voluntary before mandatory).

2.3. Voluntary language switching task

Following previous studies (de Bruin et al., 2018; Jevtović et al., 2020), the voluntary language switching task is a picture-naming task in which the pictures are accompanied with a ‘voluntary cue’. In the task, participants were given the following instructions: “In the following part you can name the pictures in Chinese or English. You can switch between languages whenever you want. You should name the pictures without over-thinking, using the word that first comes to mind. Do not use the same language during the whole task.” There were four blocks in the voluntary switching task. Each block consisted of 61 trials and the first one was regard as filler trial. Fig. 1 illustrates the procedure for one trial. As shown in the figure, a fixation cross was first presented in the center of the computer screen for 250 ms followed by a blank screen for 500 ms. The ‘voluntary cue’ (i.e., an Asian face and a Western face) then appeared for 500 ms followed by a blank screen for 250 ms. A target picture was presented and disappeared when participant verbally responded or after 2000 ms. Finally, a blank screen was presented for 1000 ms before the next trial began with a fixation point. Participants' RTs were recorded by a Chronos response box which was connected to a microphone. Accuracy of verbal responses was checked using EV Capture, a screen recording software which recorded the entire experimental session.

2.4. Mandatory language switching task

The mandatory language switching task was administered after the voluntary switching task and included one practice block and four formal blocks. Each formal block consisted of 61 trials (i.e., one filler trial, 30 switch trials, and 30 repeat trials) and all trials were presented pseudo-randomly. The pictures used in the mandatory language switching task were the same as in the voluntary language switching task. The procedure was also the same except that in the mandatory switching task, participants had to name the pictures in a specific language according to which of the two faces was clear (i.e., a ‘mandatory cue’): in Chinese when the Asian face is clear and the Western face is blurry; and in English when the Western face is clear and the Asian face is blurry (see Fig. 1).

Table 1
Means (SDs) of participants' self-ratings of language abilities.

	L1 (Chinese)	L2 (English)	*t*	*p*
Listening	6.00 (0.85)	3.59 (1.29)	8.95	< 0.001
Speaking	5.79 (1.01)	3.76 (1.19)	8.46	< 0.001
Reading	5.97 (0.87)	4.52 (1.21)	6.00	< 0.001
Writing	5.66 (0.94)	4.03 (0.91)	7.83	< 0.001
Average	5.85 (0.81)	3.97 (0.94)	10.20	< 0.001

2.5. EEG data recording and pre-processing

EEG data were recorded at a sampling rate of 1000 Hz from 64 Ag/AgCl electrodes placed according to the extended 10–20 positioning system. Data were filtered online with a bandpass between 0.05 and 0.100 Hz and referenced online to the right mastoids (TP10). Impedances were kept below 5 kΩ. EEG data preprocessing was performed offline using EEGLAB (Delorme and Makeig, 2004) after error response trials and filler trials were removed. Data were re-filtered with a bandpass between 1 and 40 Hz and re-referenced to the average of all electrodes. Ocular artifact reduction was performed through ICA component rejection. The continuous recording was segmented into epochs ranging from −200 ms to 800 ms relative to the picture stimuli. Baseline correction was performed in reference to pre-stimulus activity. Epochs with voltages exceeding ±80 μV were automatically discarded.

2.6. Data analyses

Both behavioral data and picture-locked ERP data from the two language switching tasks were analyzed with mixed-effects models in R using the lme4 package (Bates et al., 2014) and the lmerTest package (Kuznetsova et al., 2014). For each model, the fixed effects included task (mandatory, voluntary), language (L1, L2), type (repeat, switch) and their interactions. All variables were coded using contrast coding (i.e., mandatory = −0.5, voluntary = 0.5; repetition = −0.5, switch = 0.5; L1 = −0.5, L2 = 0.5), yielding tests of the main effects directly analogous to that obtained from an ANOVA. Participants and items were included as random effects. We started with a full model including all fixed effects, random intercepts for participants and items, and random slopes for all variables (Barr et al., 2013), and when models did not converge, we followed a backward-fitting procedure to identify a model that would converge. Following this, for all significant interactions with task (mandatory and voluntary), separate submodels were conducted for both switching tasks.

For the behavioral data, we first identified and excluded from further analysis, three types of incorrect responses, including no or late responses, incorrect picture names uttered, and responses given in the incorrect language. We also excluded from the analyses the first filler trial of each block and all incorrect responses (3.12 %), RTs beyond mean ± 2.0 SD (2.9 %) or <150 ms (1.4 %) and >1500 ms (2.3 %). We did not conduct analyses on the accuracy rates given that it was above 95 %.

For the ERP data, we focused on picture-locked N2 and LPC components of two switching tasks. Based on previous studies on language switching (Liu et al., 2020; Timmer et al., 2019), the N2 and LPC components were analyzed in time-windows of 200–350 ms and 400–600 ms, respectively. We analyzed the mean amplitude of the waveform across the selected time-windows of N2 (frontal: F3, F1, FZ, F2, F4; frontal- central: FC3, FC1, FCZ, FC2, FC4; and central: C3, C1, CZ, C2, C4) and LPC (frontal: F3, F1, FZ, F2, F4; frontal-central: FC3, FC1, FCZ, FC2, FC4; and central: C3, C1, CZ, C2, C4; central-parietal: CP3, CP1, CPZ, CP2, CP4; and parietal: P3, P1, PZ, P2, P4).

3. Results

3.1. Behavioral performance

Table 2 presents the mean (and SD) RTs from the mandatory and

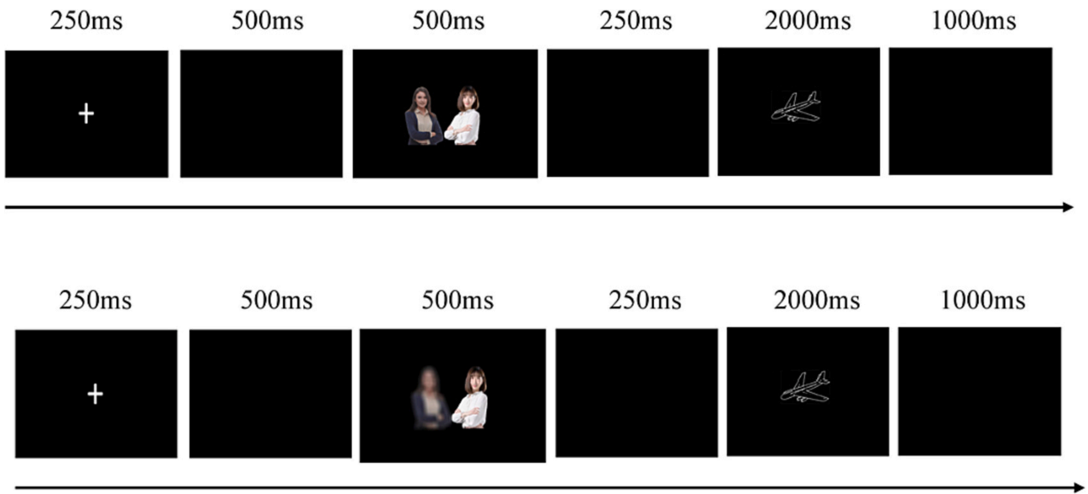

Fig. 1. Procedure of the Voluntary (Upper Panel) and Mandatory Language Switching (Lower Panel).

Table 2
Mean (and SD) RTs for mandatory and voluntary language switching.

	Mandatory		Voluntary	
Trial Type	L1 Chinese	L2 English	L1 Chinese	L2 English
Repeat	842 (100)	799 (86)	846 (113)	825 (85)
Switch	883 (111)	833 (97)	872 (110)	835 (84)

Table 3
Mixed-effects model for RTs.

Fixed Effects	Estimate	*SE*	*t*	*p*
(Intercept)	845.40	18.12	46.66	< 0.001
Task	6.82	10.63	0.64	0.526
Language	−35.89	8.67	−4.14	< 0.001
Type	29.14	3.11	9.37	< 0.001
Task × Language	22.23	5.54	4.01	< 0.001
Task × Type	−15.19	5.55	−2.74	0.006
Language × Type	−9.13	5.54	−1.65	0.099
Task × Language × Type	−3.99	11.07	−0.36	0.718

voluntary language switching tasks and Fig. 2 illustrates the switch costs in each language. The model for RTs included task, language, type, and their interactions as the fixed effects, as well as the by-participant random slope and the by-item random slope for task, language, type. As shown in Table 3, the model found a significant effect of type, $t = 9.37$, $p < .001$, indicating a switch cost (a quantitative index of reactive control) in which switch trials elicited slower responses (M = 856 ms) than repeat trials (M = 828 ms). Importantly, the interaction between task and type reached significance, $t = -2.74$, $p = .006$. Further analyses showed slower RTs in switch trials compared to repeat trials in both mandatory (repeat trials: 820 ms; switch trials: 858 ms; $t = 7.32$, $p < .001$) and voluntary (repeat trials: 836 ms; switch trials: 855 ms; $t = 4.62$, $p < .001$) switching tasks. A significant interaction between task and type indicated that the switch cost in mandatory switching ($M = 38$ ms) was larger than in voluntary switching ($M = 19$ ms). The main effect of task and the interaction between language and type were not significant (*ps* > 0.05). Moreover, the three-way interaction between task, language, and type was not significant ($p = .718$), indicating that the patterns of (asymmetric) switch costs varying between the two languages does not depend on mandatory or voluntary switching contexts.

There was a significant main effect of language, $t = -4.14$, $p < .001$, with slower RTs in the L1 ($M = 861$ ms) compared to the L2 ($M = 823$ ms). This suggests a reversed language dominance effect (a quantitative index of proactive control). The interaction between task and language was significant, $t = 4.01$, $p < .001$, such that there were slower RTs in the L1 ($M = 862$ ms) compared to the L2 ($M = 816$ ms) in both mandatory language switching, $t = -5.41$, $p < .001$, and voluntary language

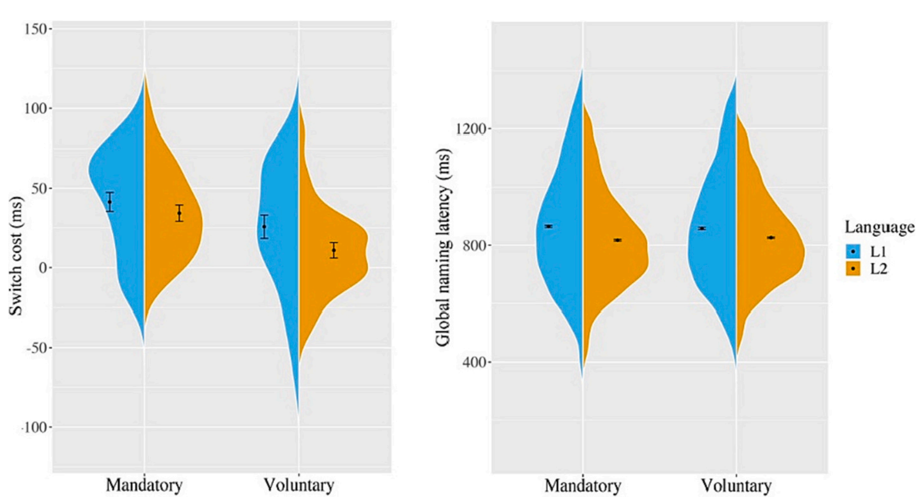

Fig. 2. RTs of Switch Costs (left panel) and the Reversed Language Dominance Effect (Right Panel) for Mandatory and Voluntary Language Switching. Note: Error bars represent standard errors.

switching (L1: 859 ms; L2: 831 ms; $t = -2.59$, $p = .013$).

3.2. ERP results

3.2.1. N2 (200–350 ms)

Figs. 3 and 4 show the grand average ERP waveforms elicited in the mandatory and voluntary language switching tasks. The structure for the linear model of N2 amplitude is the same as the model on RTs. As shown by Table 4, for reactive control, the model on the N2 component showed a significant effect of type, $t = 2.31$, $p = .027$, indicating a larger N2 effect in repeat trials ($M = -0.83$ μV) than switch trials ($M = -0.76$ μV). More importantly, the interaction between task and type reached significance, $t = -2.02$, $p = .043$. Further sub-model analyses indicated that repeat trials ($M = -0.78$ μV) elicited larger N2s than switch trials ($M = -0.60$ μV) in mandatory language switching, $t = 2.79$, $p = .009$, but not in the voluntary language switching task (repeat trials: −0.88 μV; switch trials: −0.92 μV; $t = 0.96$, $p = .339$). Moreover, the three-way interaction between task, language, and type was significant ($t = 3.03$, $p = .002$), demonstrating different neural switch cost patterns for N2 in mandatory compared to voluntary language switching. To analyze the exact patterns of switch costs for the two language switching contexts, separate sub-models were conducted. In mandatory language switching, we found a significant interaction between language and type, $t = -2.497$, $p = .013$, indicating an *asymmetrical switch cost* (L1: 0.29 μV vs. L2: 0.06 μV). In contrast, the interaction between language and type in voluntary language switching was not significant ($p = .099$), indicating a *symmetrical switch cost* (L1: −0.05 μV vs. L2: −0.03 μV). For proactive control, however, the statistical analyses failed to show a significant effect of language ($p = .375$) or a significant interaction between task and language ($p = .991$). This suggests that there are similar *reversed language dominance effects* between the two switching tasks.

3.2.2. LPC (400–600 ms)

The structure for the linear model of LPC amplitude was the same as the model on RTs. As shown in Table 5, for the reactive control, the model yielded a significant effect of type, $t = -2.55$, $p = .013$, showing larger LPCs in repeat trials ($M = 0.26$ μV) than in switch trials ($M = 0.21$ μV). The interaction between task and type was significant, $t = 2.03$, $p = .043$. Further sub-model analyses indicated that repeat trials ($M = 0.26$ μV) elicited larger LPCs than switch trials ($M = 0.20$ μV) in the mandatory language switching, $t = -3.29$, $p = .002$, but not in the voluntary language switching task (repeat trials: 0.25 μV; switch trials: 0.22 μV; $t = -0.51$, $p = .612$). Moreover, the three-way interaction of task, language, and type was significant, $t = 2.57$, $p = .010$. Further sub-model analyses found a significant interaction between language and type, $t = -2.22$, $p = .026$, in mandatory language switching, indicating an *asymmetrical switch cost* (L1: −0.02 μV vs. L2: −0.10 μV). However, in the voluntary language switching task, the interaction between language and type was not significant ($t = 1.25$, $p = .211$), indicating a *symmetrical switch cost* (L1: −0.03 μV vs. L2: −0.02 μV).

Regarding proactive control, the model revealed a significant effect of language, $t = 2.30$, $p = .029$, indicating larger LPCs in the L2 ($M = 0.27$ μV) compared to the L1 ($M = 0.20$ μV). Critically, the interaction between task and language reach significance. $t = -2.40$, $p = .016$. Further analyses indicated that, L2 trials ($M = 0.27$ μV) elicited larger LPCs than L1 trials ($M = 0.19$ μV) in mandatory language switching, $t = 3.25$, $p = .003$, but not in voluntary switching (L1 trials: 0.21 μV; L2 trials: 0.26 μV; $t = 0.66$, $p = .516$).

4. Discussion

The present study investigated the extent to which inhibitory control is involved in voluntary language switching and whether there are differences in the time-course of inhibitory control during voluntary and mandatory switching. Behavioral data showed that switch costs and the reversed language dominance effect emerged in both switching contexts, but they were larger in mandatory compared to voluntary language switching. ERP data revealed that N2 and LPC amplitudes of switch costs in mandatory language switching were significantly larger than the amplitudes of switch costs in voluntary switching. Conversely, the significant difference in the reversed language dominance effect between mandatory and voluntary switching was only observed on LPC amplitude. Overall, these findings suggest that inhibitory control is functional in both mandatory and voluntary language switching, but that time-course and relative strength of inhibition of the two tasks are distinct.

4.1. The existence of inhibitory control in voluntary language switching

The ICM (Green, 1998) holds that a bilingual's two languages are activated during speech production and that competition between the two languages is mediated by inhibitory control. In language switching

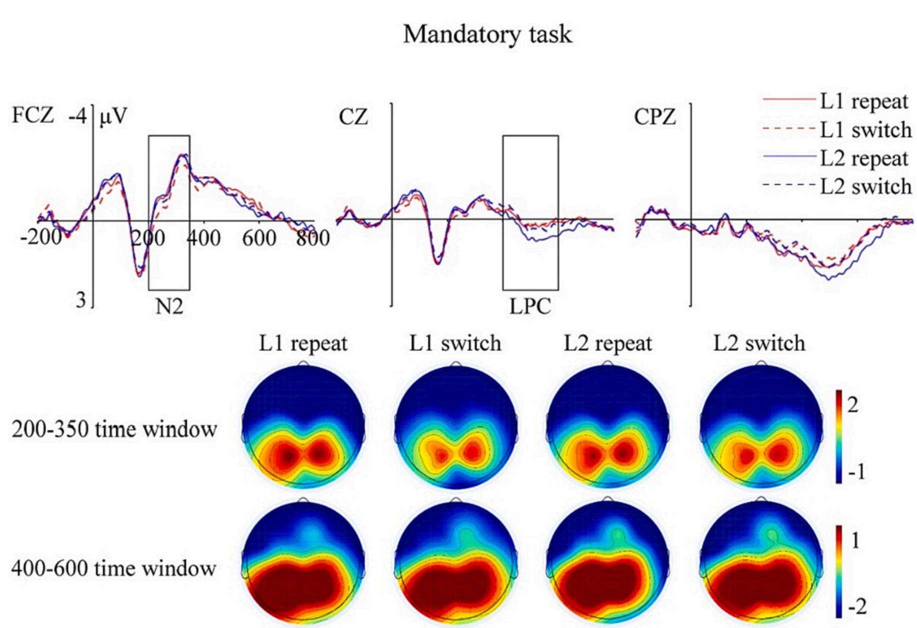

Fig. 3. Grand Average Waveforms (Upper Panel) and Topographic Maps (Lower Panel) of Mandatory Language Switching per Language and Trial Type.

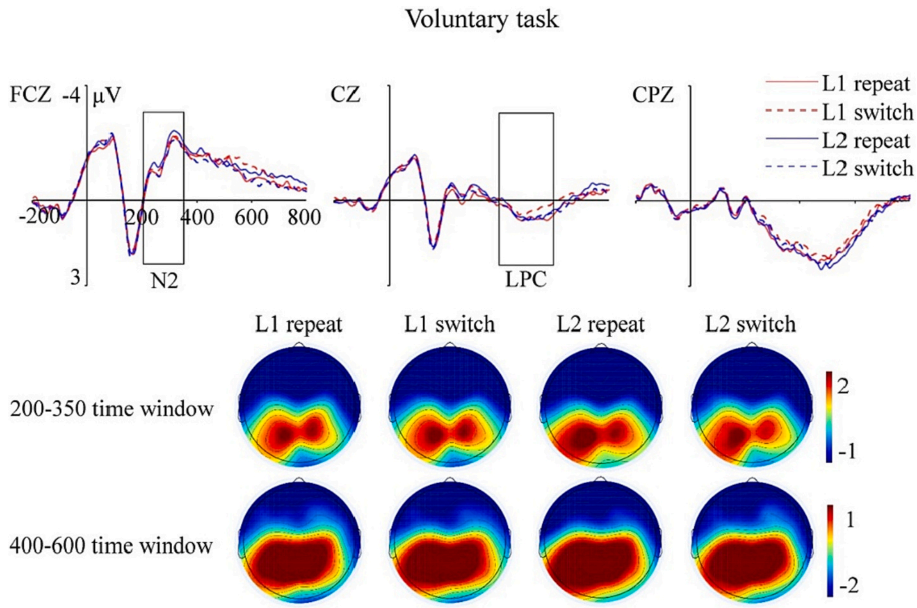

Fig. 4. Grand Average Waveforms (Upper Panel) and Topographic Maps (Lower Panel) of Voluntary Language Switching per Language and Trial Type.

Table 4
Mixed-effects model for N2.

Fixed effects	Estimate	*SE*	*t*	*p*
(Intercept)	−0.80	0.25	−3.14	0.004
Task	−0.21	0.12	−1.77	0.088
Language	−0.04	0.05	−0.90	0.375
Type	0.11	0.05	2.31	0.027
Task × Language	0.00	0.07	−0.01	0.991
Task × Type	−0.14	0.07	−2.02	0.043
Language × Type	−0.03	0.07	−0.46	0.644
Task × Language × Type	0.41	0.13	3.03	0.002

Table 5
Mixed-effects model for LPC.

Fixed effects	Estimate	*SE*	*t*	*p*
(Intercept)	0.23	0.06	3.72	0.001
Task	0.01	0.05	0.19	0.851
Language	0.05	0.02	2.30	0.029
Type	−0.04	0.01	−2.55	0.013
Task × Language	−0.06	0.03	−2.40	0.016
Task × Type	0.05	0.03	2.03	0.043
Language × Type	−0.01	0.02	−0.57	0.571
Task × Language × Type	0.13	0.05	2.57	0.010

contexts, the model argues that bilinguals inhibit the non-target language to reduce cross-language interference and to access words in the target language successfully. Accordingly, compared to repeat trials, switch trials in both mandatory and voluntary switching consume more cognitive resources to overcome the interference of non-target language. However, according to the lexical accessibility account, switch costs should be observed when a word in the non-target language is more readily accessible than in the target language (Gross and Kaushanskaya, 2015) rather than exerting inhibition on one language, indicating that there may not be a local switch cost or global reversed language dominance effect. For instance, Gollan and Ferreira (2009) found that bilinguals preferred to switch into their non-dominant language when naming highly accessible items and into their dominant language when naming less accessible items. In the present study, switch costs emerged in voluntary language switching and is consistent with findings from previous studies (Gollan and Ferreira, 2009; Jevtović et al., 2020), suggesting that reactive control was recruited in voluntary language switching. We also observed the reversed language dominance effect in voluntary switching, which implies the involvement of proactive control.

However, previous studies revealed that proactive control may not be necessary during voluntary language switching as evidenced by mixing benefits instead of mixing costs (de Bruin et al., 2018; Jevtović et al., 2020). Regarding such differences, we argue that future studies should consider various indexes (e.g., mixing costs, the reversed language dominance effect, and blocked language-order effects; for a review, see Declerck, 2020) to investigate the role of proactive control in voluntary language switching. Moreover, individual differences such as language proficiency should be considered in future work on voluntary language switching. As far as we know, the participants recruited in most of the previous studies on voluntary language switching were balanced bilinguals. Given that the participants we examined in the present study were unbalanced bilinguals, we speculate that individual differences in L2 proficiency may contribute to the inconsistent findings regarding proactive control during voluntary language switching.

Despite observing behavioral evidence in the current study for switch costs and the reversed language dominance effect in voluntary language switching, analyses on the ERP data revealed no neural switch costs or reversed language dominance effect. These findings were in line with a recent study in which transcranial direct current stimulation (tDCS) and EEG were used to examine the role of inhibitory control in voluntary language switching (Liu et al., 2020). They found no neural switch cost on N2 or LPC amplitudes during voluntary switching. Liu et al.'s study and the present study are the only two ERP experiments to have been conducted thus far on voluntary language switching. However, both studies have examined these effects among Chinese-English unbalanced bilinguals. Future studies should strive to include bilinguals of various languages and proficiency levels.

4.2. *Inhibitory control in voluntary vs. mandatory language switching*

In comparing inhibitory control in voluntary and mandatory language switching, for reactive control, the behavioral data showed that switch costs were larger in mandatory switching compared to voluntary switching. This finding was in line with a previous study conducted by Jevtović et al. (2020) in which highly-proficient bilinguals, who had begun learning their L2 at a very early age, named pictures voluntarily or mandatorily. The results showed that switch costs existed in both mandatory and voluntary language switching but that these effects were more costly in mandatory language switching. Together, these findings underscore the distinct patterns of reactive inhibitory control between voluntary and mandatory language switching. For proactive control, the behavioral data revealed the reversed language dominance effect (i.e., a quantitative index of proactive control) in both tasks and such effect was larger in mandatory language switching compared to voluntary switching. It is noteworthy that Jevtović et al. also found a smaller mixing effect for voluntary compared to mandatory language switching. However, in mandatory switching, the mixing effect was a *cost* and in voluntary switching, the mixing effect was a *benefit*. These findings are different from our results showing the reversed language dominance effect in both switching contexts, which suggests that proactive control was involved during both. It must be noted that the bilingual participants in Jevtović et al.'s study and those in the present study have very different levels of L2 proficiency: whereas Jevtović et al. examined highly-proficient bilinguals, we investigated individuals with significantly less proficiency in their L2. These differences in proficiency may explain various degrees of involvement of proactive control during language switching (see Schwieter and Sunderman, 2008 for a discussion on how language control is affected by L2 proficiency).

From the ERP findings, we observed that switch costs on both N2 and LPC amplitudes in mandatory language switching were significantly larger than in voluntary switching, suggesting that there is a different pattern of reactive control which underpins mandatory and voluntary language switching. In contrast, for proactive control, the difference in the reversed language dominance effect between mandatory and voluntary language switching was only observed on LPC amplitude. This indicates a different electrophysiological mechanism of reactive and proactive inhibitory control between voluntary and mandatory language switching. Our findings accord with previous studies which argue that both N2 and LPC reflect reactive control (Egner and Hirsch, 2005; Zhang et al., 2020) while only LPC reflects proactive control (Rainey et al., 2021; Timmer et al., 2019).

Taken together, our findings support the ACH, which proposes that bilingual language control processes dynamically adapt to different interactional contexts. On a behavioral level, both reactive and proactive control corresponded to significantly higher quantitative indicators in mandatory language switching than in voluntary switching, indicating that in the mandatory task, both local and global inhibition was called upon to a larger degree than in the voluntary task. On an electrophysiological level, ERP analyses showed that the difference in time-course of inhibitory control between both switching contexts can be found more intuitively and accurately. To the best of our knowledge, this is the first experiment using EEG to compare language control in mandatory and voluntary language switching.

5. Conclusion

The present study examined whether inhibitory control is utilized in voluntary language switching and if so, whether there are time-course differences in inhibitory control during mandatory and voluntary language switching. At the behavioral level, we found reactive and proactive control in both mandatory and voluntary switching contexts, and the degree of inhibitory control in mandatory language switching was larger than in voluntary language switching. With respect to the time-course of inhibitory control, there were significant differences in reactive control during mandatory and voluntary language switching as indicated by N2 and LPC amplitudes, while the difference in proactive control between both switching contexts was only observed in LPC amplitude. Overall, these findings provide new and important electrophysiological evidence explaining differences in the neurocognitive mechanisms underlying voluntary and mandatory language switching.

Data availability

Data will be made available on request.

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