

# Effects of language context on executive control in unbalanced bilinguals: An ERPs study

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## Funding information

The study is supported by the National Natural Science Foundation of China (31970976) for Baoguo Chen

## Abstract

The influence of the language context on language control has been widely discussed in the bilingualism literature, and there is an increase in studies examining the effect of language context on domain-general executive control. However, it remains unclear how language contexts affect executive control performance. In the present study, we created single- and mixed-language comprehension contexts. Unbalanced Chinese-English bilinguals completed a modified flanker task that was interleaved with a single-language or mixed-language picture-word matching task. The effects of language comprehension context on language control were reflected by the N2 and LPC effects. Executive control processes also differed depending on the language comprehension context, with faster behavioral responses and larger N2 but smaller P3 electrophysiological components in the mixed-language context. Moreover, the LPC amplitude in the mixed-language context predicted the behavioral performance in the executive control task. These findings suggested that flexible language control during language comprehension altered executive control processes in unbalanced bilinguals.

## KEYWORDS

bilingualism, ERPs, executive control, language context

## 1 | INTRODUCTION

The relationship between language control and executive control has been the focus of much work in the bilingualism literature. However, the question whether bilingualism is related to executive control remains controversial (see reviews in Bialystok, 2017; Lehtonen et al., 2018). A recent trend in this field has paid more attention to the role language contexts might play (Green & Abutalebi, 2013; Jiao, Grundy, Liu, & Chen, 2020; Jiao, Liu, Liang, et al., 2019). Some studies have suggested that executive control may be influenced by the language context that bilinguals are exposed to, showing the beneficial effects of being exposed to a mixed-language

context on executive control (Jiao, Liu, Liang, et al., 2019; Wu & Thierry, 2013). Using EEG, the current study aimed to examine the effects of single-language and mixed-language comprehension contexts on both language control and executive control.

### 1.1 | The effects of bilingualism on executive control

Many studies have suggested that the two languages of a bilingual are activated in parallel (e.g., Marian & Spivey, 2003). Control mechanisms are needed to manage this competing activation during bilingual language processing. While there is no full agreement on the relationship between language control and executive control in bilinguals, some studies have

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proposed that general executive control mechanisms are used to control language competition. This use of executive control mechanisms might facilitate executive control performance in bilinguals (see review in Bialystok, 2017).

Early studies on the relationship between bilingualism and executive control focused on comparisons between bilinguals and monolinguals. For example, Costa and colleagues (2008) compared the performance of monolingual and bilingual young adults in the attentional network task (ANT) that taps into three networks, including alerting, orienting and executive control (Costa, Hernández, & Sebastián-Gallés, 2008). The results revealed that bilinguals outperformed monolinguals in terms of the alerting network and executive control, suggesting that bilingualism exerted a positive effect on attentional networks.

More recent research has focused on the role language contexts can play within bilinguals. This approach has manipulated the language context bilinguals are in while completing an executive control task (e.g., Adler, Valdés Kroff, & Novick, 2020; Jiao, Liu, Liang, et al., 2019). For example, Jiao and colleagues conducted a behavioral study in which they created single- and mixed-language comprehension contexts using a cross-task adaptation paradigm. They compared how unbalanced bilinguals performed on executive control tasks interleaved with different language contexts (Jiao, Liu, Liang, et al., 2019). This approach not only provided the possibility to measure language control and executive control simultaneously, but also ruled out potential confounds that can arise when comparing different participant groups. In the current study, we used the same approach to investigate how language context during language comprehension affects both language control and executive control.

## 1.2 | The role of language context

The importance of language context has been widely discussed in the bilingualism literature. The theoretical motivation investigating the language context effect may come from the language-mode framework and adaptive control hypothesis (Green & Abutalebi, 2013; Grosjean, 2001, 2013). The language-mode continuum framework proposed that there is a continuum representing the activation of two languages in diverse language modes (i.e., language contexts in the present study) and defined two typical language contexts, namely, a single-language context and a mixed-language context. Bilinguals in a single-language context only use one language (e.g., language A) when they are interacting with others who have no knowledge of the other language (e.g., language B). During single-language contexts, bilinguals have to lower the activation of nontarget language to avoid language intrusions or inappropriate switching. When bilinguals are interacting

with others who share their languages and are switching between two languages, they are in a more mixed-language context. Both languages are active as potential candidates in a mixed-language context (Green & Abutalebi, 2013; Grosjean, 2001, 2013). The other popular theory regarding the role of language context is the adaptive control hypothesis (Green & Abutalebi, 2013). The adaptive control hypothesis focuses on the adaptability of active control demands on languages according to the language context, emphasizing the effect of language context on language control and executive control processes. Based on real-world interactional contexts, this hypothesis specifies three different language contexts, including a single-language context, a mixed-language context, and a dense code-switching context. Bilinguals in the dense code-switching context routinely switch their languages in a single utterance, whereas in the mixed-language context, language switching may occur within a conversation with different speakers, not within an utterance. The present study mainly examined single-language and mixed-language contexts, not the dense code-switching context.

Moreover, several studies have suggested that the language context can modulate executive control. Jiao, Liu, Liang, et al. (2019) examined how the language context modulated the executive control system. A group of bilinguals performed a flanker task interleaved with a picture-word matching task, which was used to create single-language (all words presented in the same language) and mixed-language (words presented interchangeably in two languages) contexts. Behavioral performance showed that the mixed-language context facilitated responses to both congruent and incongruent flanker trials, revealing a beneficial effect of language context during word comprehension on executive control. This beneficial effect of the mixed-language context on the flanker task has also been supported by electrophysiological evidence, with a higher accuracy and a smaller P3 amplitude of incongruent flanker trials when the flanker task was completed during a mixed-language context than a single-language context (Wu & Thierry, 2013). This beneficial effect on incongruent flanker trials suggested that the mixed-language context affected the conflict resolution process in the flanker task.

Moreover, using sentences instead of words, one recent study further investigated the effect of language context on executive control by focusing on sentence reading (Adler et al., 2020). To examine whether comprehending a code-switch sentence affected executive control performance, a group of Spanish-English bilinguals completed the flanker task in a nonswitch (i.e., single-language) context and in a code-switch (i.e., mixed-language) context. The behavioral performance revealed that compared to nonswitch sentences, participants responded more quickly on incongruent flanker trials that followed a code-switch sentence, but the sentence context did not affect congruent flanker trials. This evidence supported the role of language context in executive control,

especially in the conflict resolution processes reflected by the flanker effect. To sum up, many studies have shown facilitative effects of mixed-language contexts on executive control. One potential explanation proposes that real-time language control processes during mixed-language context might trigger executive control engagement and might subsequently facilitate executive control performance.

Considering the effects of language context on language control and executive control simultaneously, Jiao et al. (2020) used a flanker task interleaved with a picture naming task and conducted an ERPs study manipulating context during language production. In both single- and mixed-language contexts, language control was measured by a picture naming task, and executive control was measured by the flanker task consisting of congruent and incongruent trials. This study not only revealed an effect of language context on language processing, but also revealed effects on executive control processing, with a larger N2 but smaller P3/LPC amplitude of the flanker task in the mixed-language context. These findings suggested that language control processes could change in response to the language context, and speculated that changes in language control might be related with adjustments in executive control. However, Jiao et al. (2020) only examined language production. Given that there might be distinct control processes during language comprehension versus production (e.g., Blanco-Elorrieta & Pylkkänen, 2016), it is necessary to study the simultaneous effects of language context on language control and executive control during language comprehension.

In brief, there is much evidence for a role of language context during language control and executive control, but it is still unclear how language contexts affect executive control, a question that is tested in our study. Previous studies have argued that context effects on executive control are related with differences in language control in different language contexts. According to the adaptive control hypothesis (Green & Abutalebi, 2013), different executive control processes might be recruited to coordinate languages in a mixed-language context than in a single-language context and the activation of these executive control mechanisms might affect subsequent performance during executive control tasks (e.g., flanker task, Adler et al., 2020; Jiao et al., 2020; Jiao, Liu, Liang, et al., 2019). Hence, we consider how the language context affects language control and executive control at the same time. We hypothesized that the effect of language context on executive control could be predicted by differences in language control during single-language and mixed-language contexts.

### 1.3 | The present study

Based on previous studies (Adler et al., 2020; Jiao et al., 2020; Jiao, Liu, Liang, et al., 2019), the present study

used a flanker task interleaved with a picture-word matching task, and examined the effects of completing the picture-word matching task in a single-language context versus in a mixed-language context. There are two strengths of this type of paradigm. On the one hand, this paradigm is able to measure real-time language control and executive control at the same time. Combined with the high temporal resolution of EEG, it is possible to separate the two types of control processes. On the other hand, this paradigm has been widely used in similar studies, thus improving the comparability between the present study and previous relevant studies (e.g., Adler et al., 2020). We created three language contexts using a picture-word matching task, namely a Chinese (L1) context, an English (L2) context, and a Chinese-English mixed-language context. The reason for establishing two single-language contexts was based on the language-mode continuum framework, which specifies that language contexts are made up of two aspects—the target language and the comparative level of activation of the two languages (Grosjean, 2013). For unbalanced bilinguals, the stronger L1 has been argued to have direct access to meaning while the weaker L2 might require mediation via the L1-translated equivalent (see details in Revised Hierarchical Model, Kroll & Stewart, 1994). Therefore, at least for the unbalanced bilinguals in our study, the L1 and L2 contexts should be viewed as two different modes in the language-mode continuum. The flanker task was used to measure executive control and included congruent and incongruent trials (Dong & Zhong, 2017; Jiao et al., 2019a, 2020; Wu & Thierry, 2013). Based on relevant studies (Jiao, Liu, Liang, et al., 2019), we speculated that the language context would affect behavioral performance during the flanker task, with shorter flanker RTs in the mixed-language context than in single-language contexts. Moreover, we expected that the effect of language context would be observed in both congruent and incongruent flanker trials in behavioral performance.

Using EEG gives us the opportunity to measure temporal aspects of language control and executive control in the same paradigm to explore how language contexts affect executive control performance. Based on previous ERPs studies in the bilingualism literature, the present study focused on the N2 and LPC components in the language control task (Jiao et al., 2020; Liu, Liang, Dunlap, Fan, & Chen, 2016), and the N2 and P3 components in flanker task (Jiao et al., 2020; Kousaie & Phillips, 2017; Wu & Thierry, 2013). Specifically, the N2 and LPC, respectively, have been associated with the language task schema competition phase and the lexical selection response phase (Liu et al., 2016). As such, we expected the N2 effect to reflect differences in inhibition of the nontarget language and to mainly be elicited by the comparison between the Chinese and English single-language contexts requiring proactive control over the nontarget language. The LPC effect has been widely discussed in bilingual

language switching tasks, with a larger LPC in switch trials than nonswitch trials (e.g., Liu et al., 2016). While the N2 effect has been associated with inhibition, the LPC is associated with the selection of the lemma in the intended language (Martin et al., 2013) and represents releasing the previously suppressed L1/L2 lemma (Jackson, Swainson, Cunningham, & Jackson, 2001). Given the presence of language switches in the mixed-language context, we hypothesized that the language control task would elicit a larger LPC in the mixed-language context than in single-language contexts.

With respect to the executive control components, the N2 and P3 are two ERP components that have been studied in the bilingualism literature. The N2 is a negative-going wave peaking between 200–350 ms after stimulus onset with an anterior scalp distribution. The N2 effect in nonverbal cognitive tasks mainly reflects conflict detection processes (van Veen & Carter, 2002a, 2002b). The N2 amplitude appears to be increased in conditions that involved high conflict and in conditions that allocate more resources to conflict processing in an early stage (Grundy, Anderson, & Bialystok, 2017; Jiao et al., 2020). As such, we speculated that the N2 component in the flanker task would reveal an effect of language context, with a larger N2 effect in the mixed-language context than in single-language contexts. The P3 component is a broad positive-going wave peaking around 300–500 ms, reflecting response inhibition, stimulus categorization, and resource allocation (Polich, 2007). Moreover, the P3 latency has been associated with the difficulty of stimulus categorization (Kok, 2001). In the bilingualism literature, one ERPs study compared monolingual and bilingual older adults in three executive control tasks, including Stroop, Simon, and flanker tasks (Kousaie & Phillips, 2017). The results showed that in the Stroop task the bilingual group outperformed the monolingual group on both behavioral and electrophysiological indicators. The bilinguals showed a higher accuracy and faster response in behavioral performance accompanied with an earlier N2 latency and larger P3 amplitude. In contrast, Wu and Thierry (2013) showed a smaller P3 amplitude during the incongruent flanker trials in mixed-language context in comparison with single-language contexts. Based on above studies, there is no consensus on the P3 component and effects of bilingualism/language context on executive control. Hence, the present study will interpret the P3 effect on the basis of the participants' behavioral performance.

In sum, the present study aimed to explore how the language context affected the executive control system by measuring the effects of language context on language control and executive control simultaneously. Moreover, the present study conducted a regression analysis to examine whether real-time language control processing was associated with behavioral performance on the executive control task. Given previous studies (e.g., Adler et al., 2020; Jiao et al., 2020), we predicted that the language context would modulate the

**TABLE 1** Means and *SDs* of AoA and language proficiency in four language skills

	L1 (Chinese)	L2 (English)	<i>t</i>	<i>p</i>
AoA	–	8.6 (1.8)	–	–
OPT	–	38 (4.6)	–	–
Listening	5.6 (0.5)	3.7 (1.2)	7.52	<.001
Speaking	5.3 (0.5)	3.3 (1.1)	8.27	<.001
Reading	4.6 (1.0)	2.6 (1.1)	10.88	<.001
Writing	4.9 (1.0)	2.8 (1.4)	6.42	<.001

Note: AoA = the age of L2 acquisition; OPT = the score of the Oxford Placement Test.

control processes in the language control task and in the executive control task. This is to say, if the language context effect on executive control results from the modulation of language control, the measures of language control should predict the executive control performance in the different language contexts. If (changes in) executive control are not related to language control, there should be no relationship between the language control measures and executive control performance.

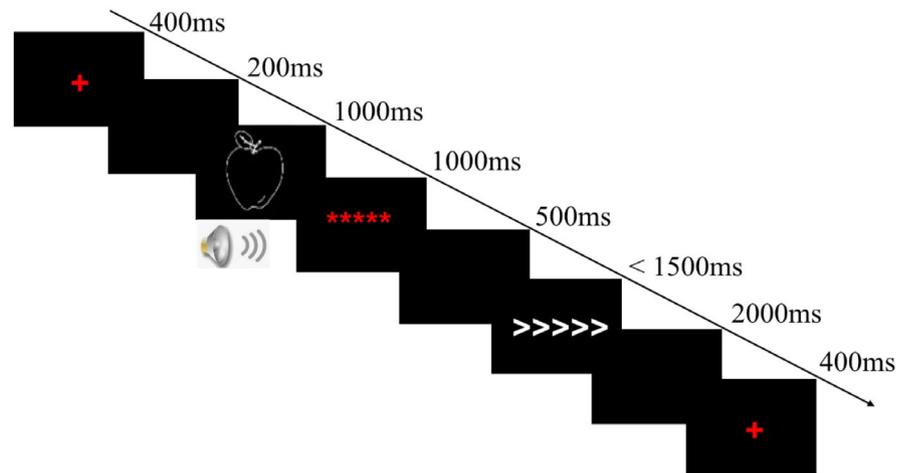
## 2 | METHOD

### 2.1 | Participants

Twenty-three students participated in the study for monetary compensation. All participants were Chinese (L1)—English (L2) bilinguals recruited from Beijing Normal University and provided written informed consent. They were right-handed bilinguals with normal or corrected-to-normal vision. None of the participants had neurological or psychological impairments or had used psychoactive medication. Ethical approval was obtained from the Committee of Protection of Subjects at Beijing Normal University. Data from four participants were eliminated due to excessive EEG artefacts. The final sample consisted of 19 participants (18 females), aged 18 to 25 years old ( $M = 21.26 \pm 2.16$ ).

All participants were born in China and had no immigration experience or overseas education. Moreover, all participants were exposed to L1 (Chinese) from birth and learned L2 (English) at the mean age of 8.6 years in a classroom setting. Therefore, the participants were homogeneous in culture and their language learning background. Language proficiency was measured using the Oxford Placement Test (OPT) and a self-rating questionnaire (see Table 1). First, the OPT score is an objective indicator of L2 proficiency (Jiao, Liu, Wang, & Chen, 2019). The highest total OPT score is 50, and the OPT consists of 25 multiple-choice questions and a cloze test. The higher the score is, the

**FIGURE 1** Experimental procedure for the interleaved presentation of language control task and flanker task



higher the English proficiency of the participant. The subjective indicator of language proficiency was obtained using a self-rating questionnaire. The participants were asked to indicate their L1 and L2 language proficiency in listening, speaking, reading, and writing skills. Language proficiency was rated on a 6-point scale, in which 1 suggested “not proficient at all,” and 6 suggested “very proficient.” Table 1 shows the average proficiencies for L1 and L2 and the results of paired-samples *t* tests comparing the two languages in listening, speaking, reading, and writing skills.

## 2.2 | Design and procedure

This study used a 2 (congruency: congruent, incongruent)  $\times$  3 (context: L1, L2, and mixed-language) within-subjects design. A flanker task was used to measure executive control, including congruent and incongruent trials; a picture-word matching task was used to create Chinese (L1), English (L2), and mixed-language contexts.

The executive control task was a flanker task (Eriksen & Eriksen, 1974), which has been widely used to measure executive control in studies on bilingualism (Adler et al., 2020; Dong & Zhong, 2017; Jiao et al., 2020; Jiao, Liu, Liang, et al., 2019; Wu & Thierry, 2013). There were two types of trials in the flanker task, that is, congruent and incongruent trials. In congruent trials, the central target arrow pointed in the same direction as the four flanking arrows (i.e.,  $<<<<$  or  $>>>>$ ). In incongruent trials, the target arrow pointed in the opposite direction of the flanking arrows (i.e.,  $<<><<$  or  $>><>>$ ). Participants were asked to respond as quickly as possible to the pointing direction of the target arrow by pressing the left or right button (i.e., “F” or “J” button on the keyboard).

The present study used an auditory picture-word matching task to create the three language contexts. In this task, participants saw a picture presented in the centre of the

computer screen and heard a word simultaneously through headphones. The task was to judge and orally report whether the picture matched the word that they heard. To avoid language switching, the language of oral report was the same as the target language in each single-language context. In mixed-language context, participants reported in proficient Chinese throughout the block to avoid the potential confounding effect of language production switching during oral report (Jiao, Liu, Liang, et al., 2019). We used 60 black-and-white line drawings, which were selected from Snodgrass and Vanderwart’s (1980) photo gallery and were standardized by Zhang and Yang (2003). The Chinese word for each picture was a two-character word, and the English equivalents ranged from 3 to 8 letters in length. The picture familiarity of the L1 and L2 names was rated on a 7-point scale, in which 1 indicated “very unfamiliar,” and 7 indicated “very familiar.” A separate group of 25 bilinguals who had a similar language proficiency as the current participants completed the familiarity task. The paired-samples *t* test for familiarity showed no significant difference in average familiarity between L1 names ( $6.6 \pm 0.3$ ) and L2 names ( $6.6 \pm 0.2$ ),  $t(59) = -0.79$ ,  $p = .43$ . The spoken word for each picture was recorded by a female speaker in a soundproof room. Before the formal experiment, participants were familiarized with the L1 and L2 picture names to reduce errors.

To examine the effect of language contexts on executive control in bilinguals, we interleaved the language control task with the flanker task, resulting in a within-subjects design. The different language contexts were counterbalanced across participants. There were three separate blocks in the present study, namely single-L1, single-L2, and mixed-language contexts. The two single-language blocks only included L1 words or L2 words, with no language switching. In contrast, the mixed-language block contained 50% L1 words and 50% L2 words, with switching between the two languages. For each separate block, 120 picture-word matching trials and 120 flanker trials were interleaved (see Figure 1). Specifically, for the language

control task, half the trials were matching trials (i.e., matching the word and picture) and the other half were mismatching trials (i.e., mismatching the word and picture). Therefore, each picture stimulus was presented twice in every block. Similarly, the proportion of congruent trials and incongruent trials in flanker task was 1:1 in each block. A flanker trial was presented that followed each picture-word matching trial.

The detailed procedure is shown in Figure 1. A fixation first appeared in the centre of the computer screen for 400 ms; after a 200 ms blank screen, the target picture, accompanied by a sound, was presented for 1,000 ms. Afterwards, the symbol “\*\*\*\*\*” appeared, which was a signal to orally report whether there was a match between the picture and the word. The reason why we asked participants to respond verbally in the language control task is to prevent participants from confusing the response keys for the language control task and the flanker task. Participants were instructed to respond after a delay to avoid artefacts of language production contaminating the EEG signal (Christoffels, Firk, & Schiller, 2007; Liu et al., 2016). A 500 ms blank screen followed the picture-word matching task. Then, a flanker trial was presented on the screen and remained until the participant responded or for a maximum duration of 1,500 ms. Finally, there was an inter-trial interval of 2,000 ms. Participants were asked to complete a practice block before the experiment to make sure they understood the task. The practice block included 16 trials with feedback on the flanker task.

### 2.3 | Electrophysiological recordings

Electrophysiological data were recorded from 64 Ag/AgCl electrodes placed according to the extended 10–20 positioning system. The signal was recorded at a 1,000 Hz sampling rate and referenced online to the tip of the nose. Vertical and horizontal eye movements were recorded by electrodes placed on the supra- and infra-orbital ridges of the left eye (VEOG) and the outer canthi of the left and right eyes (HEOG). Impedances were maintained below 5 k $\Omega$ . Electroencephalographic activity was filtered online with a bandpass between 0.05 and 100 Hz and re-filtered offline with a 30 Hz low-pass, zero-phase shift digital filter. Based on the recording of eye movements, eye blinks were corrected for each subject by a regression-based algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986). The sampling rate was reduced to 500 Hz in offline processing, and the reference electrode was converted to bilateral mastoid (M1 and M2). In language control trials, continuous recordings were cut into epochs ranging from –100 to 800 ms relative to the onset of picture stimuli; in flanker trials, continuous recordings were cut into epochs ranging from –100 to 800 ms relative to arrow stimuli. Baseline correction was performed in reference to the prestimulus activity (–100 to 0 ms). Signals exceeding  $\pm 80$   $\mu$ V in any given epoch were automatically discarded.

## 3 | RESULTS

For both behavioral and ERP (event-related brain potential) data analysis, we conducted mixed-effects models with subjects and items as crossed random effects with R Project for Statistical Computing using the *lme4* package (Baayen, Davidson, & Bates, 2008; Bates, Maechler, Bolker, & Walker, 2014). The benefit of using mixed-effects models in favor of a traditional analysis is that mixed-effects models allowed us to consider subjects and items random effects simultaneously, making the data modeling more appropriate and the results generalizable to other subjects and items (Baayen et al., 2008).

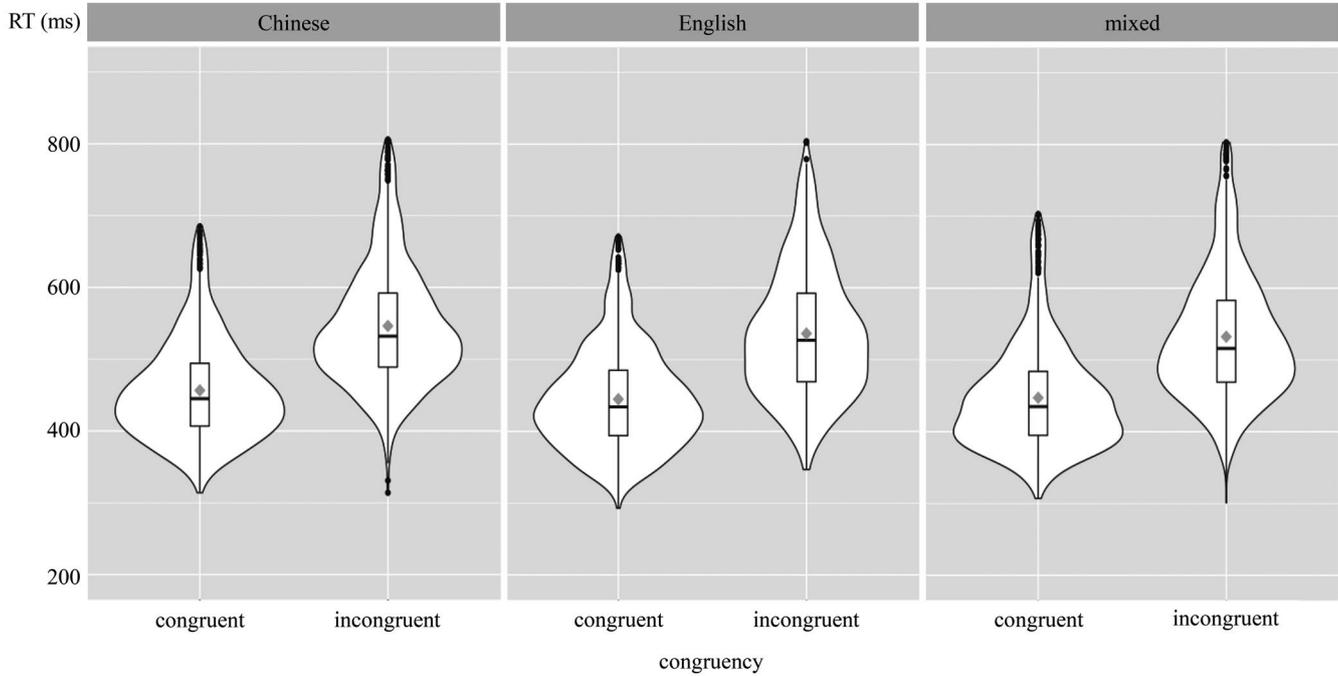
The response time (RT) and ERP data were submitted to linear mixed-effects models, and the accuracy data were submitted to logistic mixed-effects models. The models included the fixed effects of theoretical interest (congruency, context, and their interactions) and the random intercepts capturing the differences across subjects and items. We assessed the contribution of each random slope to each model using likelihood-ratio tests and reported the best-fitting model justified by the data. The variable congruency was centred (congruent = –0.5, incongruent = 0.5), and the variable context was coded by treatment coding. The results reported in each table were the best-fitting model with the mixed-language context as baseline. Then, the baseline was changed to L1/L2 context and the other significant results are also reported in the text.

### 3.1 | Behavioral results

The behavioral data analysis mainly focused on the flanker task because the accuracy in the picture-word matching task was at ceiling (>96%). For the RT analysis of the flanker task, the data from incorrect responses (2.2%), RTs less than 200 ms or more than 1,000 ms (0.9%), and RTs beyond  $M \pm 2.5SD$  (2.9%) for per trial type were excluded. For accuracy, all available data were analysed.

#### 3.1.1 | RT

Figure 2 depicts the RTs for the flanker task in the L1, L2, and mixed-language contexts. Given the theoretical interest of our study, the mixed-effects model for RT included congruency, context, and their interactions as fixed effects, as well as the by-subject and by-item random intercepts. Because the model with maximal random slopes did not converge, we used a backward-fitting procedure to identify a model that would converge. Then we continued to compare the models and included the random slopes that improved the model. As such, the RT model included the by-subject random slope for congruency and the by-item random slope for congruency.



**FIGURE 2** Violin plots showing the RTs in the flanker task for each language context [left: Chinese (L1) context; center: English (L2) context; right: mixed-language context] for each trial type (congruent and incongruent trials). The gray dot represents the mean value, while the thin horizontal black line represents the median. The violin plot outline shows the density of data points for different RTs, and the boxplot shows the interquartile range with the 95% confidence interval represented by the thin vertical black line

**TABLE 2** Fixed effects estimates for the flanker RT mixed-effects model

Fixed effects	Estimated	SE	t
(Intercept)	491.29	9.01	54.54***
Context (mixed vs. L1)	10.32	2.24	4.60***
Context (mixed vs. L2)	0.20	2.23	0.09
Congruency (C vs. I)	84.95	6.15	13.82***
Context (mixed vs. L1) × congruency (C vs. I)	4.57	4.37	1.05
Context (mixed vs. L2) × congruency (C vs. I)	6.73	4.36	1.55

Note: C = congruent; I = incongruent.

\*\*\* $p < .001$ .

Table 2 presents the fixed effects structure for the linear model of RT, with mixed-language context as a baseline. First, there was a significant effect of congruency, with slower responses for incongruent trials ( $M = 538 \pm 87$  ms) than congruent trials ( $M = 450 \pm 71$  ms). Then, the effect of context variable was significant, indicating that the RTs in the mixed-language context ( $M = 489 \pm 91$  ms) were shorter than in the L1 context ( $M = 501 \pm 89$  ms),  $t = 4.60, p < .001$ , while there was no difference between the mixed-language context and the L2 context ( $M = 489 \pm 92$  ms),  $t = 0.09, p = .93$ . Further analysis using the L2 context as the baseline showed that the RTs in the L2 context were also shorter than

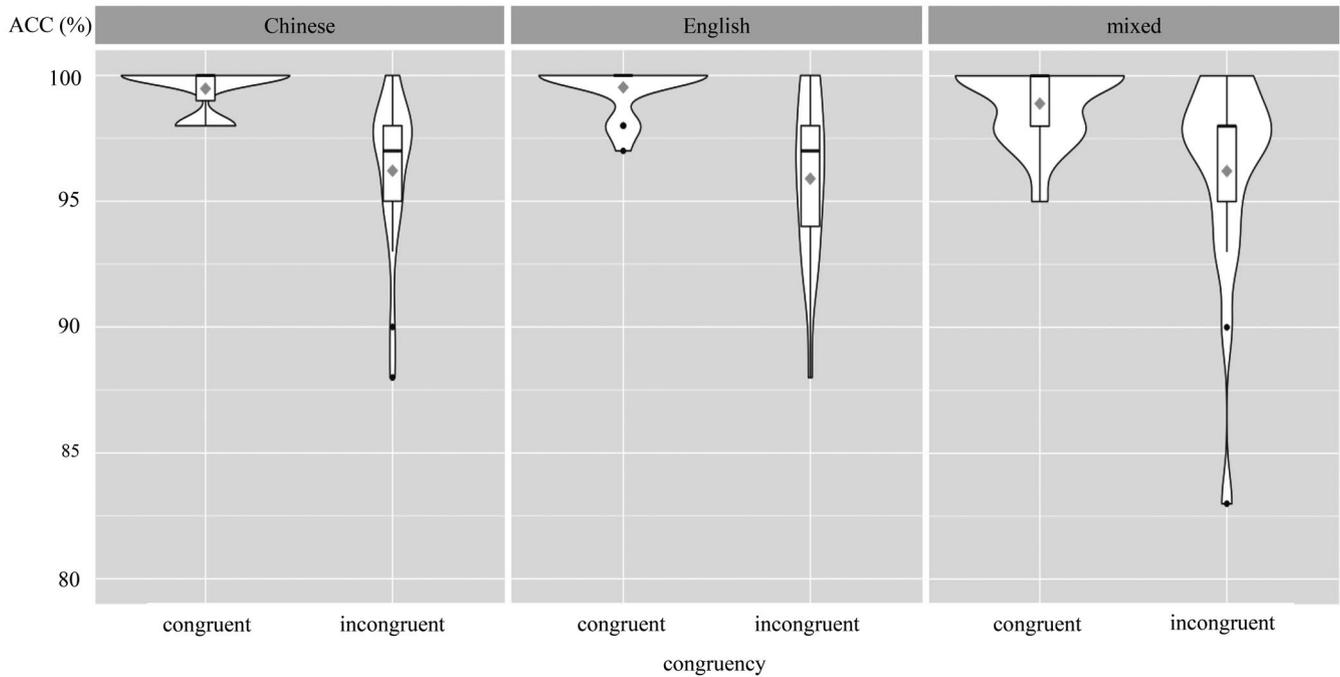
in the L1 context,  $t = 4.51, p < .001$ . There were no significant interactions.

### 3.1.2 | Accuracy

Figure 3 presents the accuracy for the flanker task based on the mean value for each condition across all participants. The accuracy data were submitted to a logistic mixed-effects model, with congruency, contexts, and their interactions as fixed effects. Subjects and items were simultaneously included as crossed random effects, with the by-subject random slope for language context and congruency. The fixed effects structure for the logistic model of accuracy is summarized in Table 3. As Table 3 shows, only the effect of congruency reached significance, with higher accuracy on congruent trials ( $M = 99\% \pm 8$ ) than on incongruent trials ( $M = 96\% \pm 19$ ). There were no other significant main effects or interactions (L1:  $M = 98\% \pm 14$ ; L2:  $M = 98\% \pm 15$ ; Mixed:  $M = 98\% \pm 15$ ).

### 3.2 | ERP results

There were three steps in the ERP data analysis. First, we analysed the effects of language context (L1, L2, mixed-language) on language control during the picture-word matching task. Based on the grand average for the picture-word



**FIGURE 3** Violin plots showing the accuracy scores in the flanker task for each language context [left: Chinese (L1) context; center: English (L2) context; right: mixed-language context] for each trial type (congruent and incongruent trial). The gray dot represents the mean value, while the thin horizontal black line represents the median. The violin plot outline shows the density of data points for different accuracy, and the boxplot shows the interquartile range with the 95% confidence interval represented by the thin vertical black line

**TABLE 3** Fixed effects estimates for flanker accuracy mixed-effects model

Fixed effects	Estimated	SE	z
(Intercept)	4.29	0.30	14.30***
Context (mixed vs. L1)	0.34	0.33	1.06
Context (mixed vs. L2)	0.28	0.32	0.86
Congruency (C vs. I)	-1.42	0.42	-3.34***
Context (mixed vs. L1) × congruency (C vs. I)	-0.83	0.58	-1.44
Context (mixed vs. L2) × congruency (C vs. I)	-0.98	0.58	-1.69

Note: C = congruent; I = incongruent.

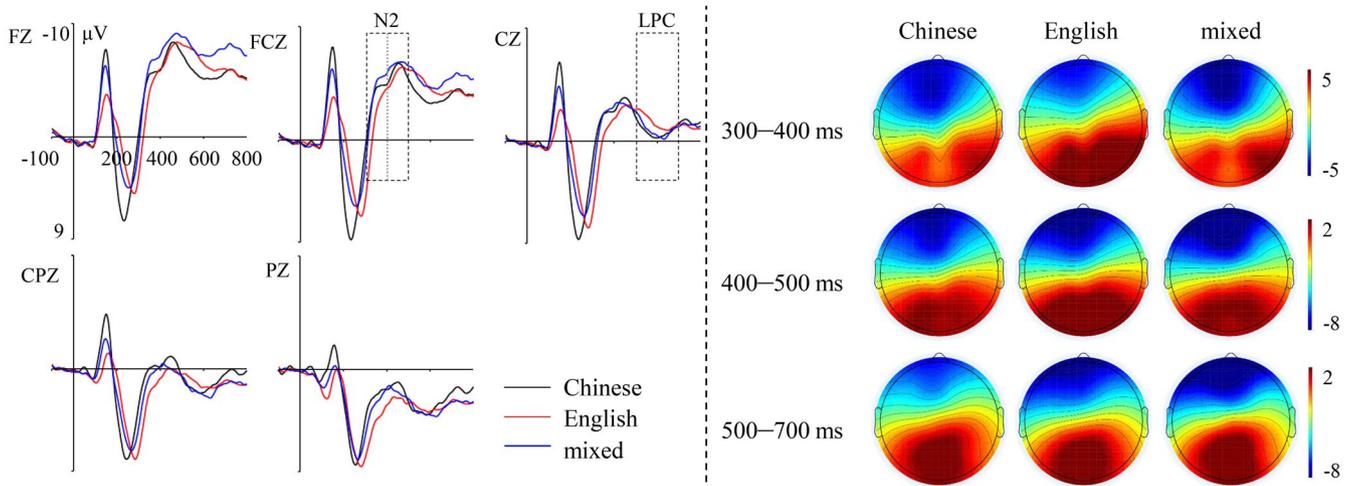
\*\*\* $p < .001$ .

matching task and previous studies examining bilingual language control (Liu et al., 2016), the N2 (F1, FZ, F2, FC1 FCZ, FC2, C1, CZ, C2) and LPC (C1, CZ, C2, CP1, CPZ, CP2, P1, PZ, P2) were analysed in the picture-word matching task. On the basis of visual inspection and previous studies, three time-windows were selected for statistical analysis, including the first time-window (300–400 ms) and the second time-window (400–500 ms) for N2 and the third time-window (500–700 ms) for LPC. There were two separate time-windows of language control for N2 because there seemed to be two peaks (Misra, Guo, Bobb, & Kroll, 2012). The second analysis focused on the flanker task. To explore the effect of

language context on executive control, we also analysed the N2 (first time-window: 200–250 ms; second time-window: 250–350 ms; F1, FZ, F2, FC1 FCZ, FC2, C1, CZ, C2) and P3 (350–550 ms; FC1 FCZ, FC2, C1, CZ, C2, CP1, CPZ, CP2) of the flanker task (Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014). We analysed the mean amplitude of the waveform across the selected time-window of each component and the latency of the maximum/minimum peak of each component. Last, we used linear regressions models to examine the relationship between language control and executive control. We used language control measures (i.e., N2 and LPC) as predictors of behavioral measures of executive control (i.e., RT). All continuous variables were centred by z-score transformation of raw scores to reduce collinearity (Tzeng, Hsu, Huang, & Lee, 2017). In addition, in order to avoid error detection in the language control trials affecting flanker trials, we only included correct flanker trials that were preceded by a correct language-trial response.

### 3.2.1 | N2 in the language control task

Figure 4 shows the grand average event-related potential waveforms elicited by the language control trials. For the N2 amplitude and latency (first time-window: 300–400 ms; second time-window: 400–500 ms), the linear mixed-effects models only included the variable context as a fixed effect, with the by-subject and by-item as crossed random effects.



**FIGURE 4** Grand average waveform (left panel) and topographic maps (right panel) of language control trials in Chinese, English and mixed-language contexts

**TABLE 4** Fixed effects estimates for mixed-effects models of N2 amplitude in the language control task

Fixed effects	300–400 ms time-window			400–500 ms time-window		
	Estimated	SE	<i>t</i>	Estimated	SE	<i>t</i>
(Intercept)	-2.42	1.13	-2.14*	-5.06	0.96	-5.25***
Context (mixed vs. L1)	-0.34	0.76	-0.45	-0.22	0.58	-0.39
Context (mixed vs. L2)	1.63	0.97	1.68	0.11	0.54	0.19
Context (L1 vs. L2)	1.97	0.55	3.58**	0.33	0.50	0.65

\*\*\**p* < .001; \*\**p* < .01; \**p* < .05.

Identical to the behavioral data analysis, treatment coding was used for the variable context, with the mixed-language context as the baseline. The fixed effects structure for the linear model of N2 amplitude is summarized in Table 4. The results of N2 amplitude during the first time-window showed that there was no difference between the mixed-language context and single-language contexts (mixed vs. L1: *t* = -0.45, *p* = .65; mixed vs. L2: *t* = 1.68, *p* = .11), but further analysis using the L1 context as a baseline revealed a larger N2 in the L1 context than the L2 context (*t* = 3.59, *p* = .002). There was no significant effect for N2 amplitude during the second time-window.

Table 5 summarized the fixed effects structure for N2 latency with the mixed-language context as a baseline. The N2 latency in the first time-window showed an earlier N2 peak in the mixed-language context (*M* = 361 ± 31 ms) than in the L2 context (*M* = 366 ± 30 ms), *t* = 3.50, *p* = .003. Further analysis using the L1 context as a baseline revealed an earlier peak of the N2 in the L1 context (*M* = 359 ± 32 ms) than the L2 context (*M* = 366 ± 30 ms), *t* = 7.03, *p* < .001). In line with the N2 amplitude results, there was no significant effect of N2 latency during second time-window. Given that the N2 effect of language context was mainly present in the comparison between the two single-language contexts, Tables 4 and 5 also reported the results of the comparison between the L1 and L2 contexts.

### 3.2.2 | LPC in the language control task

The linear model for the LPC (500–700 ms) was the same as the mixed-effects model for the N2. Tables 6 and 7 present the fixed effects structure for the linear models of the LPC amplitude and latency, respectively. The results of the LPC amplitude revealed a larger LPC in the mixed-language context than in the L1 context (*t* = -2.25, *p* = .02) and than in L2 context (*t* = -3.03, *p* = .002), with no significant difference between the two single-language contexts (*t* = -0.73, *p* = .47). For the LPC latency, Table 7 showed no significant differences between the mixed-language context (*M* = 602 ± 63 ms) and the single-language context (L1: *M* = 599 ± 64 ms, *t* = -1.22, *p* = .24; L2: *M* = 599 ± 64 ms, *t* = -1.14, *p* = .27) nor between the two single-language contexts (*t* = 0.10, *p* = .93).

### 3.2.3 | N2 in the flanker task

Figure 5 shows the grand average event-related potential waveforms elicited by congruent and incongruent trials in the L1, L2, and mixed-language contexts. Based on the visual inspection of grand average waveforms, we selected two time-windows (200–250 ms and 250–350 ms) for the

**TABLE 5** Fixed effects estimates for mixed-effects models of N2 latency in the language control task

Fixed effects	300–400 ms time-window			400–500 ms time-window		
	Estimated	SE	<i>t</i>	Estimated	SE	<i>t</i>
(Intercept)	361.37	1.27	284.10***	451.44	1.65	273.87***
Context (mixed vs. L1)	−2.62	1.52	−1.73	−0.20	1.41	−0.14
Context (mixed vs. L2)	4.84	1.38	3.50**	2.64	1.40	1.88
Context (L1 vs. L2)	7.46	1.06	7.03***	2.84	1.89	1.50

\*\*\* $p < .001$ ; \*\* $p < .01$ .**TABLE 6** Fixed effects estimates for mixed-effects model of LPC amplitude in the language control task

Fixed effects	Estimated	SE	<i>t</i>
(Intercept)	2.07	0.74	2.80*
Context (mixed vs. L1)	−0.82	0.36	−2.25*
Context (mixed vs. L2)	−1.10	0.36	−3.03**

\*\* $p < .01$ ; \* $p < .05$ .**TABLE 7** Fixed effects estimates for mixed-effects model of LPC latency in the language control task

Fixed effects	Estimated	SE	<i>t</i>
(Intercept)	602.19	2.95	204.02***
Context (mixed vs. L1)	−3.82	3.13	−1.22
Context (mixed vs. L2)	−3.53	3.08	−1.14

\*\*\* $p < .001$ .

statistical analysis of the N2 component. The N2 amplitudes and latency were submitted to the linear mixed-effects models. Each model included congruency, context and their interactions as fixed effects, and simultaneously included by-subject and by-item random effects. The variable congruency was mean-centred coded (congruent = −0.5, incongruent = 0.5), and the variable context was coded by treatment coding with the mixed-language context as a baseline. The fixed effects structure for N2 amplitude and latency are summarized in Tables 8 and 9, respectively.

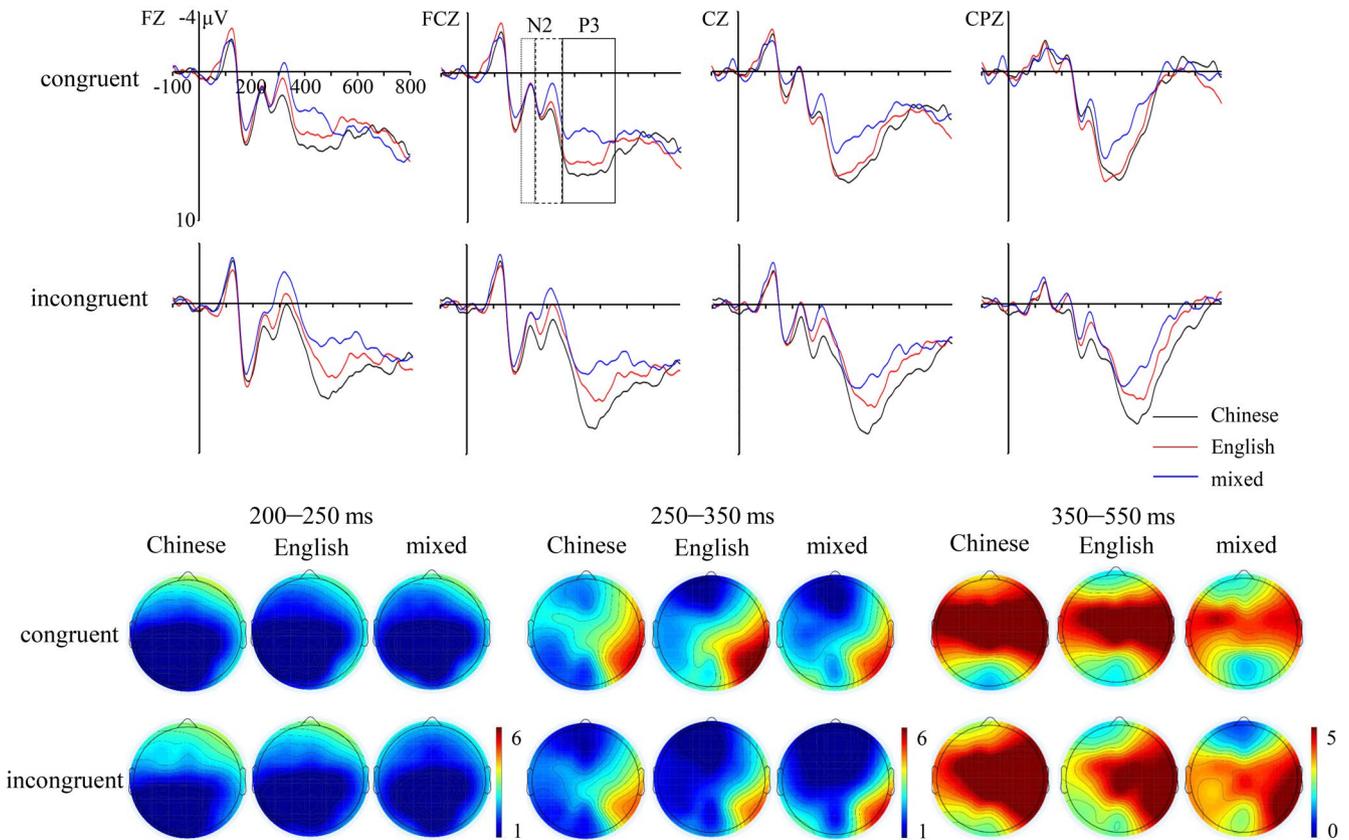
For the N2 amplitude, although there was no significant effect during the first time-window, the second time-window showed an effect of language context on the flanker task. Specifically, the results during the second time-window showed that the mixed-language context elicited the largest N2 component (mixed vs. L1:  $t = 4.11$ ,  $p < .001$ ; mixed vs. L2:  $t = 1.89$ ,  $p = .06$ ), and there was also a larger N2 in the L2 context than in the L1 context ( $t = 2.23$ ,  $p = .03$ ). Moreover, during the second time-window, there was an interaction between language context (L1 vs. mixed-language) and congruency ( $t = 1.98$ ,  $p = .05$ ). Further analysis revealed that the mixed-language context

elicited a larger N2 than the L1 context in incongruent flanker trials ( $t = 4.29$ ,  $p < .001$ ), while there was no difference between the mixed and L1 context in congruent flanker trials ( $t = 1.56$ ,  $p = .12$ ). Regarding N2 latency in the flanker task, there was a significant effect of congruency during the second time-window (250–350 ms), showing that the N2 component in congruent trials was earlier ( $M = 296 \pm 35$  ms) than the N2 component in incongruent trials ( $M = 302 \pm 35$  ms). Moreover, during the first time-window (200–250 ms), the significant congruency effect on N2 latency was also observed in the mixed-language context ( $t = 2.05$ ,  $p = .04$ ).

### 3.2.4 | P3 in the flanker task

Similar to the mixed-effect models for the N2 component, the P3 (350–550 ms) amplitude and latency were also submitted to linear models, including congruency, context, and their interactions as fixed effects. The fitted model for P3 amplitude included by-subject and by-item random effects and is summarized in Table 10. As Table 10 shows, there was a significant effect of language context, showing that the P3 amplitude is smaller in the mixed-language context than in the L1 context ( $t = 6.19$ ,  $p < .001$ ) and the L2 context ( $t = 3.56$ ,  $p < .001$ ). Further analysis using L2 as a baseline revealed that the P3 amplitude in the L2 context is also smaller than in the L1 context,  $t = 2.61$ ,  $p = .009$ . Thus, the mixed-language context elicited the smallest P3 amplitude among the three language contexts.

Table 11 summarized the fitted model for the P3 latency with the by-subject random slope for language context and congruency. The results for the P3 latency showed a significant effect of congruency, with an earlier P3 in the congruent trials ( $M = 442 \pm 65$  ms) compared to the incongruent trials ( $M = 458 \pm 59$  ms). Moreover, there was a significant interaction between language context and congruency, indicating that the flanker effect (namely subtracting the congruent trials from incongruent trials) in the L2 context (22.2 ms) is greater than in the mixed-language context (9.5 ms,  $p < .01$ ) and in the L1 context (14.7 ms,  $p = .04$ ).



**FIGURE 5** Grand average waveforms (upper panel) and topographic maps (lower panel) of congruent and incongruent flanker trials in Chinese, English and mixed-language contexts

### 3.3 | Regression analysis

Given the significant effects of language context on the behavioral performance in the flanker task, we conducted linear regression analyses to explore how language control processes affected executive control performance in the three separate language contexts. The regression models modeled the RTs in the flanker task as a function of the first N2 amplitude (300–400 ms) and the LPC amplitude from the language control task. The second N2 time-window was excluded from the predictors in the regression models because there was no language context effect during the second N2 time-window.

In the R computing environment, a linear regression analysis was conducted on the basis of the means of each language context across all participants. Table 12 presents the results of the regression models. Figure 6 visually presents the relation between the LPC amplitude in the language control task and the RT in the executive control task for L1 context (left), L2 context (middle) and mixed-language context (right). The results showed that during the two single-language contexts, neither the N2 nor the LPC significantly predicted the behavioral performance in the flanker task; but during the mixed-language context, the LPC amplitude in the picture-word matching task was a significant predictor of the overall performance in the flanker task (i.e., the average response time across congruent

and incongruent flanker trials). Specifically, an increasing LPC amplitude during the mixed-language context was associated with slower responses in the subsequent executive control task. The predictive effect of the LPC amplitude on RT performance was marginally significant during the L2 context ( $t = 1.89, p = .08$ ), but not during the L1 context.

## 4 | DISCUSSION

The present study investigated how external language contexts affect executive control performance from the perspective of language comprehension in a group of unbalanced Chinese-English bilinguals. We interleaved a flanker task with a single-L1, single-L2 and mixed-language context, and measured the language control and executive control processes at the same time. There were two main findings. First, there were significant effects of language context on language control and executive control. The results of the picture-word matching task showed a different LPC effect for mixed- and single-language contexts. The N2 component showed a difference between the L1 single-language and the L2 single-language contexts. Second, the flanker task showed shorter RTs, a larger N2, and a smaller P3 amplitude when completed in a mixed-language context. Furthermore,

**TABLE 8** Fixed effects estimates for mixed-effects model of N2 amplitude in the flanker task

Fixed effects	200–250 ms time-window			250–350 ms time-window		
	Estimated	SE	<i>t</i>	Estimated	SE	<i>t</i>
(Intercept)	1.10	0.91	1.20	1.35	0.77	1.75
Context (mixed vs. L1)	0.91	1.18	0.77	1.34	0.33	4.11***
Context (mixed vs. L2)	0.36	1.13	0.32	0.62	0.33	1.89
Congruency (C vs. I)	−0.09	0.46	−0.20	−1.82	0.47	−3.91***
Context (mixed vs. L1) × congruency (C vs. I)	1.11	0.64	1.73	1.29	0.65	1.98
Context (mixed vs. L2) × congruency (C vs. I)	0.55	0.64	0.86	0.62	0.65	0.95

Note: C = congruent; I = incongruent.

\*\*\**p* < .001.

**TABLE 9** Fixed effects estimates for mixed-effects model of N2 latency in the flanker task

Fixed effects	200–250 ms time-window			250–350 ms time-window		
	Estimated	SE	<i>t</i>	Estimated	SE	<i>t</i>
(Intercept)	226.48	1.48	152.63	300.25	2.49	120.50***
Context (mixed vs. L1)	0.46	0.54	0.85	−1.12	1.86	−0.60
Context (mixed vs. L2)	0.67	0.55	1.22	−1.41	2.07	−0.68
Congruency (C vs. I)	1.89	0.92	2.05*	4.89	1.45	3.37***
Context (mixed vs. L1) × congruency (C vs. I)	−0.72	1.08	−0.66	0.17	2.02	0.08
Context (mixed vs. L2) × congruency (C vs. I)	−0.12	1.09	−0.11	1.95	2.03	0.96

Note: C = congruent; I = incongruent.

\*\*\**p* < .001; \**p* < .05.

**TABLE 10** Fixed effects estimates for mixed-effects model of P3 amplitude in the flanker task

Fixed effects	Estimated	SE	<i>t</i>
(Intercept)	4.18	0.64	6.51***
Context (mixed vs. L1)	2.04	0.33	6.19***
Context (mixed vs. L2)	1.18	0.33	3.56***
Congruency (C vs. I)	−0.17	0.47	−0.36
Context (mixed vs. L1) × congruency (C vs. I)	0.69	0.66	1.05
Context (mixed vs. L2) × congruency (C vs. I)	−0.11	0.65	−0.17

Note: C = congruent; I = incongruent.

\*\*\**p* < .001.

the regression analyses showed that the LPC amplitude reflecting language control in the mixed-language context was associated with overall RTs in the flanker task.

#### 4.1 | The effect of language context on executive control

As mentioned in the Introduction, there are two lines of research examining the bilingualism effect on executive

**TABLE 11** Fixed effects estimates for mixed-effects model of P3 latency in the flanker task

Fixed effects	Estimated	SE	<i>t</i>
(Intercept)	447.73	4.65	96.38***
context (mixed vs. L1)	4.96	3.22	1.54
context (mixed vs. L2)	2.92	3.05	0.96
congruency (C vs. I)	10.06	4.43	2.27*
context (mixed vs. L1) × congruency (C vs. I)	4.94	3.64	1.35
context (mixed vs. L2) × congruency (C vs. I)	12.22	3.66	3.34***

Note: C = congruent; I = incongruent.

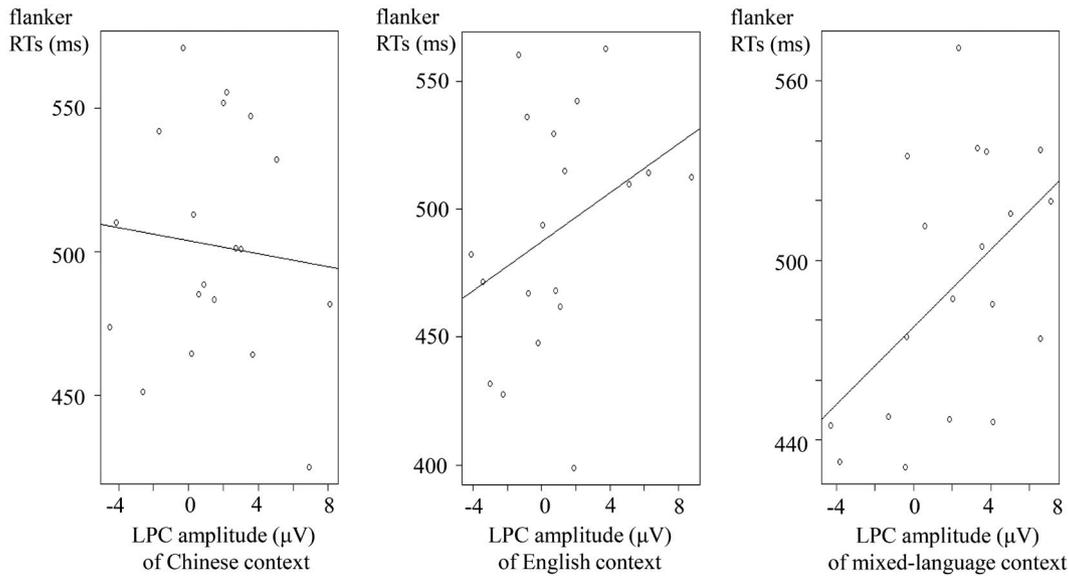
\*\*\**p* < .001; \**p* < .05.

control. One approach is to compare different groups (e.g., bilinguals and monolinguals) on executive control tasks (e.g., Costa et al., 2008; Kousaie & Phillips, 2017). For example, one ERPs study compared monolingual and bilingual older adults on the Flanker, Simon and Stroop tasks, and found some ERP differences between the two groups (Kousaie & Phillips, 2017). However, given that some studies do not show group differences in executive control performance (Paap & Greenberg, 2013), comparing bilinguals and monolinguals has not led to a consensus on the bilingual

**TABLE 12** The coefficients for linear regression models

Language context	Measures of language control	Beta	SE	t
L1	N2	0.09	0.27	0.34
	LPC	-0.13	0.27	-0.50
L2	N2	-0.29	0.24	-1.19
	LPC	0.46	0.24	1.89
Mixed	N2	0.17	0.22	0.77
	LPC	0.47	0.22	2.15*

\* $p < .05$ .



**FIGURE 6** The relation between language control measures and executive control measures

advantage effect. These mixed results might come from confounds and individual differences affecting between-subjects comparisons.

It is important to acknowledge that bilingualism consists of multifaceted experiences and it has been argued that language control processes change when bilinguals are exposed to different language contexts (Green & Abutalebi, 2013). Recent work has, therefore, studied whether exposure to different language contexts can modulate executive control (Adler et al., 2020; Jiao, Liu, Liang, et al., 2019; Wu & Thierry, 2013). In the present study, a group of unbalanced bilinguals completed a modified flanker task in L1, L2, and mixed-language contexts. In line with previous studies, our findings found better behavioral flanker performance in the mixed-language context as compared to single-language contexts. In addition, the mixed-language context showed a larger N2 but smaller P3 during flanker trials. These findings showing an effect of language comprehension contexts are consistent with one recent study examining the effect of language production contexts on language control and executive control (Jiao et al., 2020), suggesting that language

contexts play a role in language control and executive control processes in unbalanced bilinguals.

Compared with two single-language contexts, the faster behavioral performance in the flanker task in the mixed-language context provided direct evidence that the mixed-language context enhanced subsequent executive control performance. Moreover, flanker responses were also faster in the L2 context compared with the L1 context. The bilinguals participating in the present study were unbalanced and more dominant in their L1 than L2. As a consequence, the L1 and L2 single-language contexts might have recruited different types and/or amounts of control. While the dominant L1 might have direct access to word meaning, the less-dominant L2 might rely on L1-translation equivalents (Kroll & Stewart, 1994). The L2 context might, thus, have been closer to a mixed-language context than the L1 context. Furthermore, unbalanced bilinguals might need to control the more dominant L1 more strongly during L2 use than vice versa (e.g., Green, 1998). Thus, the L2 context might have recruited more control and might subsequently have had a stronger effect on the flanker task than the L1 context.

In addition, compared to single-language contexts, the effect of mixed-language context on executive control performance suggested that language switching control in mixed-language context might play a part. This explanation was supported by previous studies. For example, Verreyt and colleagues discovered the key role of language switching by comparing three groups of bilinguals, namely unbalanced bilinguals, balanced nonswitching bilinguals, and balanced switching bilinguals (Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016). The behavioral performance in executive control tasks showed that the balanced switching bilinguals performed better than the other groups of bilinguals who had less experience with language switching. Moreover, from the perspective of language comprehension, the present study found the effect of mixed-language context across congruent and incongruent trials in the flanker task, consistent with previous studies investigating the relationship between bilingual language comprehension and executive control. For instance, one correlational study focused on the relationship between language comprehension and executive control in a group of Dutch-French bilinguals, and revealed a significant correlation between the switch costs in a bilingual categorization task and the global response time in a Simon task (Struys, Woumans, Nour, Kepinska, & Van den Noort, 2019). This finding indicated that language control during bilingual language comprehension was closely related to monitoring mechanisms, as measured by the global performance in the executive control task (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Struys et al., 2019).

Combined with the larger N2 but smaller P3 in the mixed-language context, we speculate that the language switching processes in the mixed-language context triggered the engagement of executive control processes and affected the flanker trials. Based on the viewpoint of Grundy et al. (2017), the increasing N2 but decreasing P3 tendency in the mixed-language context suggested that, when performing the flanker task in a mixed-language context, participants relied more on early cognitive processes, such as conflict monitoring and detection, leading to a lower demand on cognitive resources during later stages, as reflected by the P3 time-window. Moreover, the interaction between congruency and language context (L1 vs. mixed) indicated that the mixed-language context played a more important role for incongruent trials than for congruent trials, with faster conflict resolution in the mixed-language context than in L1 context.

Moreover, the regression models between language control and executive control revealed a potential relationship between the two types of control in the mixed-language context. In general, the LPC amplitude in the bilingualism literature reflects lexical control over nontarget lemmas, with larger control demands eliciting larger LPC (Liu et al., 2016). Compared to the single-language contexts where bilinguals applied proactive control over the nontarget language, in

the mixed-language context bilinguals relied more on control at the lexical level to resolve competition because both languages were potential candidates. Therefore, one possible explanation for the relationship between language control and executive control in the mixed-language context is that the changed language control demands in this context might affect the involvement of executive control and the cooperation between two types of control, leading to changes in the flanker task. The regression analyses showed that bilinguals with a larger LPC in the mixed-language context showed longer flanker RTs. This is inconsistent with the overall analyses showing a larger LPC in the mixed- compared to single-language contexts in combination with shorter flanker RTs in the mixed-language context. Further research is needed to examine the exact relationship between measures of language control and executive control.

Given there are various factors modulating P3 amplitude, an alternative explanation of the present findings is that the electrophysiological differences in P3 amplitude were caused by task difficulty for unbalanced bilinguals. In general, greater task difficulty is associated with a larger P3 amplitude. If so, the more difficult mixed-language context should have elicited a larger P3 in comparison to easier single-language contexts. Instead, in our study, there was a reduced P3 amplitude in the flanker task completed in the mixed-language context, excluding the potential confounding factor of task difficulty. An alternative explanation is based on P3 amplitude as an indicator of resource availability, with a larger P3 amplitude reflecting greater resource availability (Kok, 2001). Combined with previous P3 effects in the bilingualism literature (Kousaie & Phillips, 2017; Wu & Thierry, 2013), the smaller P3 effect in the mixed-language context in our study might reflect a lower demand on cognitive resources during later response stages (350–550 ms) because more cognitive resources have been allocated during early stage. In addition, our findings showing a smaller P3 amplitude are not consistent with Wu and Thierry (2013), who found that the mixed-language context elicited a smaller P3 only in incongruent flanker trials. It may be related to the different tasks used to create language contexts, namely the picture-word matching task in our study and the presentation of word stimuli without any response in the study of Wu and Thierry (2013).

## 4.2 | The effect of language context on language control

Considering the language context effect on language control and executive control at the same time was one of the contributions of our study. The importance of language context has been emphasized by the adaptive control hypothesis (Green & Abutalebi, 2013) and has been widely discussed in

bilingualism studies. For example, one study investigated language control in contexts involving mostly the use of a dominant or of a nondominant language (Timmer, Christoffels, & Costa, 2019) and revealed that language context modulates the functioning of bilingual language control.

In the present study, we also revealed effects of language context on language control functioning, reflected by the N2 and LPC in the picture-word matching task. The possible explanation for these findings is that the activation levels of two languages are changed according to the language context (Grosjean, 2001). The N2 is an indicator of whole-language control in the language task schema competition phase (Jackson et al., 2001; Liu et al., 2016). The N2 effect in our study appeared on the contrasts between L1 and L2 single-language contexts and signified that unbalanced bilinguals triggered different language control patterns to control the activation levels of two languages in dominant and non-dominant language contexts.

Moreover, there were differences between single- and mixed-language contexts in the LPC amplitude, with a larger LPC amplitude in the mixed-language context. The LPC mainly reflects language control in the lexical selection response phase in the bilingualism literature (Jackson et al., 2001; Liu et al., 2016). Given that both languages are potential target languages in the mixed-language context, bilinguals could prefer to rely on control at the lexical level to achieve fluent language switching.

The current study focused on unbalanced bilinguals. If we want to have a more comprehensive understanding of the role of language context, we need to also consider balanced bilinguals who are highly proficient in both L1 and L2. Our study is a first step to examine how language context changes the functioning of language control and executive control, but many other factors, such as language proficiency and cultural context, could also potentially influence the control processes in these two domains.

## 5 | CONCLUSION

To conclude, using high temporal resolution EEG, our study sheds light on the flexibility of language control and executive control during different language comprehension contexts. Compared with single-language contexts, Chinese-English bilinguals made more use of control at the lexical level during the mixed-language context, reflected by the LPC component in the picture-word matching task. The language context also affected executive control processes, with a larger N2 but smaller P3 in the flanker task during the mixed-language context. Furthermore, the language control process in the mixed-language context was associated with the behavioral performance during the flanker task. In conclusion, we show that manipulating language comprehension

contexts can alter language control and executive control processes within unbalanced bilinguals.

## CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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## REFERENCES

- Adler, R. M., Valdés Kroff, J. R., & Novick, J. M. (2020). Does integrating a code-switch during comprehension engage cognitive control? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*(4), 741–759. <https://doi.org/10.1037/xlm0000755>
- Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. <https://doi.org/10.1016/j.jml.2007.12.005>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. *R Package Version*, *1*(7), 1–23.
- Bialystok, E. (2017). The bilingual adaptation: How minds accommodate experience. *Psychological Bulletin*, *143*(3), 233–262. <https://doi.org/10.1037/bul0000099>
- Blanco-Elorrieta, E., & Pykkänen, L. (2016). Bilingual language control in perception versus action: MEG reveals comprehension control mechanisms in anterior cingulate cortex and domain-general control of production in dorsolateral prefrontal cortex. *Journal of Neuroscience*, *36*(2), 290–301. <https://doi.org/10.1523/JNEUROSCI.2597-15.2016>
- Christoffels, I. K., Firk, C., & Schiller, N. O. (2007). Bilingual language control: An event-related brain potential study. *Brain Research*, *1147*, 192–208. <https://doi.org/10.1016/j.brainres.2007.01.137>
- Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition*, *113*(2), 135–149. <https://doi.org/10.1016/j.cognition.2009.08.001>
- Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, *106*(1), 59–86. <https://doi.org/10.1016/j.cognition.2006.12.013>
- Dong, Y., & Zhong, F. (2017). Interpreting experience enhances early attentional processing, conflict monitoring and interference suppression along the time course of processing. *Neuropsychologia*, *95*, 193–203. <https://doi.org/10.1016/j.neuropsychologia.2016.12.007>
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149. <https://doi.org/10.3758/BF03203267>
- Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, *1*(2), 67–81. <https://doi.org/10.1017/S1366728998000133>
- Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology*, *25*(5), 515–530. <https://doi.org/10.1080/20445911.2013.796377>
- Grosjean, F. (2001). The bilingual's language modes. In J. Nicol (Ed.), *One mind, two languages: Bilingual language processing* (pp. 1–22). Oxford, UK: Blackwell.

- Grosjean, F. (2013). Bilingual and monolingual language modes. In Chapelle, C. (Ed.), *The encyclopedia of applied linguistics* (pp. 489–493). Oxford, UK: Blackwell.
- Grundy, J. G., Anderson, J. A., & Bialystok, E. (2017). Neural correlates of cognitive processing in monolinguals and bilinguals. *Annals of the New York Academy of Sciences*, 1396, 183–201. <https://doi.org/10.1111/nyas.13333>
- Jackson, G. M., Swinson, R., Cunnington, R., & Jackson, S. R. (2001). ERP correlates of executive control during repeated language switching. *Bilingualism: Language and Cognition*, 4(2), 169–178. <https://doi.org/10.1017/S1366728901000268>
- Jiao, L., Grundy, J. G., Liu, C., & Chen, B. (2020). Language context modulates executive control in bilinguals: Evidence from language production. *Neuropsychologia*, 142, 107441. <https://doi.org/10.1016/j.neuropsychologia.2020.107441>
- Jiao, L., Liu, C., Liang, L., Plummer, P., Perfetti, C. A., & Chen, B. (2019). The contributions of language control to executive functions: From the perspective of bilingual comprehension. *Quarterly Journal of Experimental Psychology*, 72(8), 1984–1997. <https://doi.org/10.1177/1747021818821601>
- Jiao, L., Liu, C., Wang, R., & Chen, B. (2019). Working memory demand of a task modulates bilingual advantage in executive functions. *International Journal of Bilingualism*, 23(1), 102–117. <https://doi.org/10.1177/1367006917709097>
- Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, 38(3), 557–577. <https://doi.org/10.1017/s0048577201990559>
- Kousaie, S., & Phillips, N. A. (2017). A behavioural and electrophysiological investigation of the effect of bilingualism on aging and cognitive control. *Neuropsychologia*, 94(8), 23–35. <https://doi.org/10.1016/j.neuropsychologia.2016.11.013>
- Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language*, 33(2), 149–174. <https://doi.org/10.1006/jmla.1994.1008>
- Lehtonen, M., Soveri, A., Laine, A., Järvenpää, J., de Bruin, A., & Antfolk, J. (2018). Is bilingualism associated with enhanced executive functioning in adults? A meta-analytic review. *Psychological Bulletin*, 144(4), 394–425. <https://doi.org/10.1037/bul0000142>
- Liu, H., Liang, L., Dunlap, S., Fan, N., & Chen, B. (2016). The effect of domain-general inhibition-related training on language switching: An ERP study. *Cognition*, 146, 264–276. <https://doi.org/10.1016/j.cognition.2015.10.004>
- Marian, V., & Spivey, M. (2003). Competing activation in bilingual language processing: Within- and between-language competition. *Bilingualism: Language and Cognition*, 6(2), 97–115. <https://doi.org/10.1017/S1366728903001068>
- Martin, C. D., Strijkers, K., Santesteban, M., Escera, C., Hartsuiker, R. J., & Costa, A. (2013). The impact of early bilingualism on controlling a language learned late: An ERP study. *Frontiers in Psychology*, 4, 815. <https://doi.org/10.3389/fpsyg.2013.00815>
- Misra, M., Guo, T., Bobb, S. C., & Kroll, J. F. (2012). When bilinguals choose a single word to speak: Electrophysiological evidence for inhibition of the native language. *Journal of Memory and Language*, 67(1), 224–237. <https://doi.org/10.1016/j.jml.2012.05.001>
- Moreno, S., Wodniecka, Z., Tays, W., Alain, C., & Bialystok, E. (2014). Inhibitory control in bilinguals and musicians: Event related potential (ERP) evidence for experience-specific effects. *PLoS One*, 9(4), e94169. <https://doi.org/10.1371/journal.pone.0094169>
- Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, 66(2), 232–258. <https://doi.org/10.1016/j.cogpsych.2012.12.002>
- Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128–2148. <https://doi.org/10.1016/j.clinph.2007.04.019>
- Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*, 23(6), 695–703. <https://doi.org/10.1111/j.1469-8986.1986.tb00696.x>
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, 6(2), 174–215. <https://doi.org/10.1037//0278-7393.6.2.174>
- Struys, E., Woumans, E., Nour, S., Kepinska, O., & Van den Noort, M. (2019). A domain-general monitoring account of language switching in recognition tasks: Evidence for adaptive control. *Bilingualism: Language and Cognition*, 22(3), 606–623. <https://doi.org/10.1017/S1366728918000342>
- Timmer, K., Christoffels, I. K., & Costa, A. (2019). On the flexibility of bilingual language control: The effect of language context. *Bilingualism: Language and Cognition*, 22(3), 555–568. <https://doi.org/10.1017/S1366728918000329>
- Tzeng, Y.-L., Hsu, C.-H., Huang, Y.-C., & Lee, C.-Y. (2017). The acquisition of orthographic knowledge: Evidence from the lexicality effects on N400. *Frontiers in Psychology*, 8, 433. <https://doi.org/10.3389/fpsyg.2017.00433>
- van Veen, V., & Carter, C. S. (2002a). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience*, 14, 593–602. <https://doi.org/10.1162/0898929020045837>
- van Veen, V., & Carter, C. S. (2002b). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiology & Behavior*, 77(4–5), 477–482. [https://doi.org/10.1016/S0031-9384\(02\)00930-7](https://doi.org/10.1016/S0031-9384(02)00930-7)
- Verreyt, N., Woumans, E. V. Y., Vandelandotte, D., Szmalec, A., & Duyck, W. (2016). The influence of language-switching experience on the bilingual executive control advantage. *Bilingualism: Language and Cognition*, 19(1), 181–190. <https://doi.org/10.1017/S1366728914000352>
- Wu, Y. J., & Thierry, G. (2013). Fast modulation of executive function by language context in bilinguals. *Journal of Neuroscience*, 33(33), 13533–13537. <https://doi.org/10.1523/JNEUROSCI.4760-12.2013>
- Zhang, Q., & Yang, Y. (2003). The determiners of picture naming latency. *Acta Psychologica Sinica*, 35(4), 447–454.

**How to cite this article:** Jiao L, Liu C, de Bruin A, Chen B. Effects of language context on executive control in unbalanced bilinguals: An ERPs study. *Psychophysiology*. 2020;00:e13653. <https://doi.org/10.1111/psyp.13653>