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The switching between newly learned languages impacts executive control

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Abstract

Previous research has explored the relationship between language control and executive control based on performance in bilinguals' skilled languages. However, this relationship between bilingualism and executive control has not been examined at the very initial stage of language learning. In the present study, we trained Chinese speakers to learn words in German and Japanese, two languages with which they had no prior experience. In pre- and post-training, we measured participants' electrophysiological data to investigate how switching between these two newly learned languages affected executive control. We observed that, while lacking the language switching effect in the behavioral data, a flanker task elicited larger N2 and P3 amplitudes in the post-training session when participants were required to switch between German and Japanese compared to when they responded to only German or Japanese. These results provided evidence of language control of newly learned languages on domain-general executive control, specifically at the (very) initial period of language learning. Our findings support the adaptive nature of the relationship between bilingual language control and executive control.

KEYWORDS

ERPs, executive control, language switching, N2, newly learned languages, P3

1 | INTRODUCTION

Over the past few decades, a number of studies in bilingualism have examined the relationship between language control and domain-general executive control (Bialystok, 2017; Costa et al., 2008; Jiao, Grundy et al., 2020; Linck et al., 2020; Pelham & Abrams, 2014; Sullivan et al., 2014; Timmer et al., 2019). Based on the widely accepted phenomenon that for bilinguals, both languages are active during speech production and comprehension (Costa et al., 2017; Kroll et al., 2015), the relationship between language control and executive control has been evident in both language switching studies (Linck et al., 2012; Liu et al., 2016) and research examining the cognitive effects of bilingualism on non-linguistic executive control (Adler et al., 2020; Jiao, Liu, et al., 2019; Liu et al., 2019). However, this growing body of empirical research primarily has focused on speakers who have some degree of proficiency in their second language (L2). Consequently, the interaction between executive control and language control involving newly learned languages is unclear. Given that various language backgrounds are hypothesized to differentially shape the engagement of executive control (e.g., Zirnstein et al., 2019), more research is needed to tease apart the role of these unique language experiences, one of which taking place at the moment of initial exposure to and learning of another language. In the present study, we address this gap in the literature by using a language learning training paradigm to examine how language control processes of newly learned languages affect executive control.

1.1 | Language control and executive control

For bilinguals, it is widely accepted that both languages are active and competing, to various degrees, when reading (e.g., Dijkstra, 2005), listening (e.g., Marian & Spivey, 2003), and speaking (e.g., Kroll et al., 2006). As such, control mechanisms are necessary to monitor, and minimize cross-language interference (Green, 1998). Previous studies examining language control have highlighted the modulating effects of domain-general control processes. For example, Liu et al. (2016) reported that the inhibitory control (IC) training significantly enhanced language switching performance for bilinguals with low levels of IC. These findings suggest that training in IC can improve the speed and accuracy of language switching and that IC plays a key role during the lexical selection response phase. Other studies provide evidence for the relationship between language switching training and executive control. For example, in a pre-/post-training study by Timmer et al. (2019), two groups of bilinguals completed non-linguistic switching tasks in pre- and post-training sessions. During the training session, one group of bilinguals received language switching training and another group received blocked naming training. The results revealed that training in language switching, but not blocked naming, increased executive control performance in the post-training session, underscoring the close relationship between language switching and executive control.

The theoretical motivation for exploring the relationship between language control and executive control stems from the adaptive control hypothesis (Green & Abutalebi, 2013) and the language-mode continuum framework (Grosjean, 2013). The adaptive control hypothesis differentiates three contexts of language use among bilingual speakers: a single-language context which does not involve language switching; a dual-language context in which both languages are used but, for example, with different speakers; and a dense code-switching context in which bilinguals routinely switch between the two languages within single utterances and bring in words from one language into the other. The theory emphasizes that language control processes adapt to the unique demands of each of these contexts. Similarly, the language-mode continuum framework proposed by Grosjean establishes a continuum for representing the dynamic activation levels of two languages in various situational contexts. While both theories emphasize the adaptive changes of language control processes in different language contexts (Liu et al., 2020; Yu & Schwieter, 2018), the language-mode continuum framework addresses the continuous changes of language control processes as learning increases and language experiences accumulate. Under these assumptions, various stages of language learning, including from initial exposure, may differentially affect the executive control system (Liu, de Bruin, et al., 2021; Liu, Jiao, et al., 2021).

Recent studies have extended this adaptive hypothesis to the executive control domain (Jiao, Grundy, et al., 2020; Jiao, Liu, et al., 2019). For instance, different effects of language control on domain-general executive control, including from inhibition and monitoring accounts, have been reported (Hilchey & Klein, 2011; Struys et al., 2019). The critical role of IC mechanisms with respect to the cognitive effects of bilingualism is related to the consequences of ongoing suppression of the language not in use (see Green's, 1998, IC model). The model holds that IC mechanisms are constantly recruited to actively suppress cross- and within-language interference. Consequently, conflict resolution in general executive control domain is strengthened, which is observable through smaller conflict effects (e.g., smaller flanker effects) in bilinguals compared to monolinguals (Bialystok, 2017; Costa et al., 2008). Whereas, regarding the monitoring account, conflict monitoring mechanisms make a connection between bilingual language control and executive control processes (Struys et al., 2019). Support for the monitoring account mainly comes from performance in language switching during comprehension tasks (Jiao, Liu, et al., 2019; Struys et al., 2019). Bilingual comprehension relies more on monitoring mechanisms to correctly identify words presented and access them from the mental lexicon. The role of monitoring mechanisms can be reflected by faster response times (RTs) in conflict detection. For instance, by using a cross-task-adaptation paradigm, Jiao, Liu, et al. (2019) created single- and mixed-language comprehension contexts and examined instantaneous effects of the language context on subsequent flanker task. The results showed that the performance of flanker task in the mixed-language context (i.e., switch context) was significantly better for congruent and incongruent trials compared to the single-language context (i.e., non-switch context). These findings support the important relationship between bilingual language comprehension and general monitoring performance. In sum, inhibition and monitoring mechanisms both play a critical role in bridging language control and executive control and dynamically adjust to different language contexts.

Similar to bilingual language control that adapts to contextual demands (Green & Abutalebi, 2013; Grosjean, 2013), there are also some adaptive changes seen regarding the relationship between language control and executive control in bilinguals. However, the aforementioned findings are based on the performance of languages in which participants are well beyond the initial learning stage. We know very little about these issues at the very initial stage of learning a new language. Is language control related to executive control for newly learned languages as has been shown for languages in which bilinguals have some degree of proficiency? The present study will begin to answer this important question.

1.2 | Newly learned languages and executive control

Bilingualism is not static, but rather it should be viewed as something that not only constantly changes but also is quite variable from one individual to the next. As such, bilingualism should be defined and measured on a developmental continuum that consists of and is shaped by various language experiences (DeLuca et al., 2019). These unique experiences can modulate the relationship between language control and executive control in distinct ways and to different degrees (Bialystok, 2007; Carlson & Meltzoff, 2008). Some studies report that executive control affects learning outcomes of new languages (Kapa & Colombo, 2014; Warmington et al., 2019), supporting the engagement of executive control during the early stages of language learning. There is also research employing electroencephalography (EEG) technology which examines critical Event-Related Potentials (ERPs) during tasks involving language switching and executive control. Compared to behavioral measures, the high-temporal resolution of ERPs allows for sensitive analyses on how executive control affects language switching. For example, Liu et al. (2018) used a pre-/post-training design to investigate the effects of IC training in language switching between the first language (L1, Chinese) and a newly learned language (Korean). IC was measured for all participants who were then divided into two groups: low-IC and high-IC. In the pre- and post-training sessions, both groups were required to complete a language switching task. During the training session, the low-IC group received IC task training, while the high-IC group did not. The ERPs analyses of language switching task focused on the late positive component which reflects lexical selection processes in the intended language. The findings showed that IC training for the low-IC group led to a change in switch cost patterns and their ability to inhibit cross-language interference. The findings suggest that domain-general executive control training can affect language control processes while switching between an L1 and a newly learned language. Interestingly, when effects such as these are found, it is typically assumed that domain-general control processes lead to better learning or using a new language. However, little attention has been paid to the reverse causal possibility. Based on current evidence, it is theoretically possible that the additional employment of executive control during initial learning of a language may, in turn, improve domain-general executive control.

1.3 | The present study

Previous studies have established the relationship between language switching and executive control in skilled languages (Adler et al., 2020; Jiao, Liu, et al., 2020) and have elaborated on the predictive effects of executive control on learning outcomes of new languages (Kapa & Colombo, 2014). Advancing this body of work, the present study utilizes EEG technology, in a pre-/post-training design, to analyze the effects of switching between newly learned languages on executive control.

A group of L1 Chinese speakers received training in German and Japanese word learning through pictures and sounds. We chose German and Japanese as the new languages for two reasons. First, all participants in the present study reported no prior knowledge or experience with either of the languages. Second, given that Japanese belongs to the East Asian languages while German is closer to Western European languages (Chiswick & Miller, 2005), it is relatively easy for learners to distinguish between the two new languages. For instance, both languages have very different orthographical, phonological, and grammatical systems.

During pre- and post-training sessions, we used the cross-task-adaptation paradigm in which a flanker task was interleaved with a picture-word matching task which required participants to switch between the two newly learned languages. Following the predictions of conflict adaptation (Hsu & Novick, 2016), if language switching processes between newly learned languages engage executive control, there should be observable effects on subsequent general control processes in the flanker task. To some extent, we could answer this based only on the results of a post-learning session (see Jiao, Liu, et al., 2020). However, the present study included the pre-learning session in its analyses in order to exclude potential influences from extraneous stimuli. If such switching effects are attributed to language control processes, then these effects should be absent in the pre-training session but present in the post-training session. However, if such switching effects come from extraneous stimuli, then the effects should be observed in both the pre- and post-training sessions.

Using EEG technology gives us the opportunity to measure the temporal aspects of the effects of newly learned language switching on executive control. Regarding the effect of bilingual language control on executive control, ERPs measures of previous studies mainly concentrated on the N1, N2, and P3 components (Barac et al., 2016; Dong & Zhong, 2017; Jiao, Grundy, et al., 2020; Morales et al., 2015). Thus, combining with the theoretical interests of the present study, we also focused on the N1, N2, and P3 components of the flanker task. The N1 component is a negative-going wave occurring 100–165 ms after stimulus onset and has been reported to have scalp distribution in the occipital region (Hopf et al., 2002) and inferior temporal regions (Bokura et al., 2001). It is argued that the N1 component reflects early attentional processing (Beste et al., 2008) such as the selective attention to characteristics of stimuli. The N2 is a negative-going wave occurring between 200–300 ms after stimulus onset and has a scalp distribution located at the frontocentral electrode sites (Mathalon et al., 2003). Increased N2 amplitude signifies that more resources are being allocated to conflict monitoring and detection processes (van Veen & Carter, 2002). The P3 component is a broad positive-going wave peaking around 300–500 ms after stimulus onset. The P3 reflects stimulus categorization, conflict resolution, and inhibition (Polich, 2007) and has a typical scalp distribution located along the parietal electrode sites. We hypothesize that when compared to non-switch contexts, any behavioral and ERPs effects of controlling newly learned languages will be observed in the flanker task administered in switch context during the post-training session.

2 | METHOD

2.1 | Participants

Twenty-two L1 Chinese speakers from Beijing Normal University were recruited for the study. Four participants were excluded: one for not participating in the post-training session and three because of excessive EEG artifacts. The final sample consisted of 18 participants (12 females), aged from 18 to 25 years old (21.4 ± 2.1). All participants were right-handed and reported having normal or corrected-to-normal vision. None of the participants reported neurological or psychological impairments. All participants were exposed to Chinese from birth and had begun learning English at eight years old in a classroom setting. A self-assessment of English proficiency which was based on a 6-point scale (1 = no proficiency; 6 = very high proficiency) revealed, as expected, that compared to Chinese, all participants reported significantly less proficiency in English listening, speaking, reading, and writing (see Table 1). Research ethics approval was obtained from the Committee of Protection of Subjects at Beijing Normal University.

2.2 | Materials and procedure

The experimental procedures took place during an 8-day period. On Days 1 and 8, the participants completed a modified flanker task interleaved with a picture-word matching task in a quiet laboratory and on Days 2–7, they were trained to learn German and Japanese words. Before the experimental tasks, participants signed an informed consent form and filled out a language background questionnaire (refer back to Table 1).

TABLE 1 Mean (and *SD*s) of language proficiency in four language skills

Language skills	Chinese	English
Listening	5.72 (0.46)	3.56 (1.29)
Speaking	5.28 (0.46)	3.22 (1.21)
Reading	4.83 (0.71)	2.83 (1.15)
Writing	4.61 (0.85)	3.06 (1.47)

Note: Language proficiency was assessed on a 6-point scale (1 = no proficiency; 6 = very high proficiency).

2.2.1 | Language learning session

For 6 consecutive days (Day 2–7), the participants were trained to learn the meaning of both German and Japanese words. Participants learned new words in school via pictures and sounds and the learning session lasted approximately 15 min on each day. Given the learning time might influence learning outcomes, we emphasized the daily learning time to all participants before entering the training session and kept in contact with them. Contact was maintained with the participants via various methods of communication (e.g., e-mail, WeChat software, etc.) and their learning outcomes were tested prior to the post-training session. Regarding the selection of target words learned, we first identified 66 words and their corresponding line drawings from Snodgrass and Vanderwart's (1980) standardized picture list (Zhang & Yang, 2003). Next, we asked a control group of 20 L1 Chinese speakers with a similar L2 English proficiency level as those who participated in the present study to indicate on a 5-point scale (1 = very dissimilar, 5 = very similar) whether the German and Japanese words sounded like any words they knew in Chinese or English. Their judgments revealed that 60 words (i.e., 30 German words and their Japanese equivalents) were considered very dissimilar to Chinese and English. These 60 words were then recorded in a soundproof room by a male speaker of both German and Japanese and were subsequently used in the learning session.

We also measured the learning outcome of new words before beginning the post-training session. In an auditory picture-word matching task, participants were asked to identify if the picture they saw matched the word they heard through headphones. The mean accuracy (and standard deviation, *SD*) across German and Japanese words was 94% (*SD* = 3.75), with German (95%, *SD* = 3.87) being significantly higher than Japanese (92%, *SD* = 4.51), $t = 2.14$, $p = .04$. The auditory picture-word matching task demonstrated that participants learned the association of sounds and meaning of new words quite well, especially for German words.

2.2.2 | Pre- and post-training sessions

During pre- and post-training sessions (i.e., Days 1 and 8), we used a cross-task-adaptation paradigm in which a flanker task alternated with a picture-word matching task (Adler et al., 2020; Hsu & Novick, 2016). The cross-task-adaptation paradigm tests whether controlling newly learned languages

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initiates domain-general executive control processes that facilitate subsequent nonverbal conflict detection and resolution in real time.

In the pre- and post-training sessions, three language contexts (German, Japanese, and German-Japanese switching) were created by manipulating the picture-word matching task. Each context was presented in a separate block, and the order of the three contexts was counterbalanced among participants. There were 120 picture-word matching trials and 120 flanker trials in each task. Figure 1 showed the alternating presentation of the two tasks. First, a fixation point appeared at the center of the computer screen for 400 ms followed by a 200 ms blank screen. A word was then played through the headphones at the same time as a picture was displayed on the screen for 1,000 ms. The symbol ***** appeared, which was the cue to orally report if the picture matched the word heard. The delay report instructions aimed to avoid contamination of the EEG signal with myoelectric artifacts of language articulation (Christoffels et al., 2007; Jiao, Liu, et al., 2020). There was a 500 ms blank screen followed by a picture-word matching trial, after which a flanker trial appeared on the screen, and remained there until the participant pressed the response key or for a maximum duration of 1,500 ms. This was followed by a 2,000 ms inter-trial interval.

There were 30 German words and 30 Japanese words included in the picture-word matching trials. In the non-switch contexts, all word stimuli were presented exclusively in either German or Japanese and in the switch context, the target words alternated between German and Japanese. At the beginning of each of these contexts, the participants were told whether the context would be in German, Japanese, or both. For each context, half the trials were matched trials (i.e., the word matched the picture) and the other half were mismatched trials (i.e., the word did not match with the picture). The rational for oral response was to prevent participants from confusing the response keys for picture-word matching trials and for subsequent flanker trials. Before learning new words in the pre-training session, participants matched the picture and new word by guessing, with their accuracy achieved being at chance.

In the flanker trials, five arrows were presented on the screen, with one target central arrow and two flanking arrows on each side, consisting of congruent trials (i.e., < < < < < or > > > > >) and incongruent trials (i.e., < < > < < or > > < > >) (Eriksen & Eriksen, 1974). Participants were required to respond as quickly and accurately as possible to the direction of the central arrow by pressing the response keys (left or right key on the keyboard). In each separate context, the proportion of congruent and incongruent trials was 1:1.

2.2.3 | Electrophysiological recordings and pre-processing

Electrophysiological data were recorded using 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 reduced to 500 Hz in offline processing. The signal was referenced online at the tip of the nose and converted to the bilateral mastoid (M1 and M2) during offline processing. 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 kept below 5 kΩ. 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 participant by a regression-based algorithm (Semlitsch et al., 1986). During the flanker task trials, continuous recordings were cut into epochs

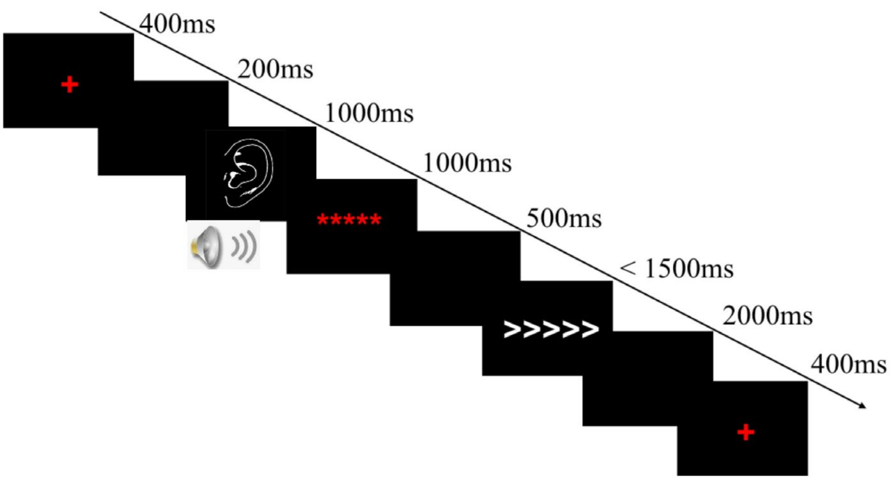

FIGURE 1 Experimental procedure for the alternating presentation of a language control task and flanker task

ranging from −100 to 800 ms relative to arrow stimuli. Baseline correction was performed in reference to the pre-stimulus activity (Jiao, Liu, et al., 2020). For each EEG data, after removing data from the faulty electrode sites, artifact detection was carried out using a voltage threshold of ±80 μV. Trials that were contaminated with movement artifacts—which consisted of 7.65% and 5.95% of the data for pre- and post-training session, respectively—were excluded from data analyses.

2.2.4 | Data analyses

In our analyses, we examined both behavioral and ERPs data elicited from the flanker tasks. All data were analyzed with mixed-effects models in R using the lme4 package (Bates et al., 2014). For each model, the fixed effects included training session (pre- vs. post-training), congruency (congruent vs. incongruent), context (German vs. Japanese vs. switch), and their interactions. Congruency and training session predictors were coded as −0.5 and 0.5. The three-level variable context was coded with orthogonal contrasts in which the first contrast compared the switch context to non-switch context (i.e., the average of German and Japanese context) and the second contrast compared the German context to Japanese context, in line with our research objectives. 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 predictors (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 training session (pre- and post-training), post-hoc tests were conducted by examining the context and congruency effects for the pre-training session and the post-training session, respectively. We reported the effect size of the findings by ANOVA.

For behavioral RTs, the data that were entered in the fitted model excluded incorrect responses (2.41%) and RTs that beyond mean ±3SD per trial-type (2.15%) (Jiao, Grundy, et al., 2020). Furthermore, we did not conduct analyses on error rates in the flanker task because the accuracy per participant was at ceiling (>95%). For the ERPs data, as N1, N2, and P3 were the main foci, we examined the mean amplitude of the waveforms across the selected time-window of each component in the flanker task. Combining the grand average for the flanker task with previous studies examining executive control (Dong & Zhong, 2017; Jiao, Grundy, et al., 2020; Jiao, Zhang, et al., 2019), the N1 and N2 were analyzed at frontocentral electrode sites (Fz, FCz, Cz) within 50–150 ms and 220–360 ms time-windows. The P3 was analyzed at centroparietal electrode sites (Cz, CPz, Pz) within the time-window of 300–500 ms.

3 | RESULTS

3.1 | Behavioral results

The RTs from the flanker task in the three language contexts are presented in Figure 2. The model for RTs included training session, context, congruency, and their interactions as the fixed effects. It also included the by-participant random slope for the training session and the by-item random slope for congruency. Table 2 presents the fixed effects structure for the RTs model. The main effect of the training session was significant, with a faster response seen in the post-training session ($M = 446 \pm 83$ ms) compared to the pre-training session ($M = 476 \pm 96$ ms), $t = -3.89$, $p < .01$, $\eta_p^2 = 0.46$. Participants responded slower during the incongruent trials ($M = 496 \pm 88$ ms) compared to the congruent trials ($M = 427 \pm 80$ ms), $t = 44.62$, $p < .001$, $\eta_p^2 = 0.97$. Moreover, the interaction between congruency and training session was significant, showing that the flanker effect in the post-training session ($M = 65$ ms) was smaller than in the pre-training session ($M = 74$ ms), $t = -3.68$, $p < .001$, $\eta_p^2 = 0.42$.

One possible explanation for the diminished RTs in the post-training session may be attributed to practice effects from the flanker task. In order to examine this possibility, for both pre- and post-training sessions, we divided all flanker trials into two groups according to whether they appeared in the first half or second half of the experiment. We then conducted the models with trial order as a fixed effect. The results showed that in the pre-training session, there was no significant difference in RTs between flanker trials in the first half of the experiment ($M = 474 \pm 92$ ms) compared to the second half ($M = 478 \pm 99$ ms) (Estimated = −6.16, $SE = 4.31$, $t = -1.53$, $p = .13$). The same was found in the post-training session: RTs for flanker trials in the first half ($M = 447 \pm 83$ ms) were no different than those in the second half ($M = 446 \pm 83$ ms) (Estimated = 0.25, $SE = 1.63$, $t = 0.15$, $p = .87$). These analyses suggest that the reduced RTs observed in the post-training session were very likely not due to practice effects.

3.2 | ERPs results

3.2.1 | N1

Figures 3 and 4 show the grand average ERPs waveforms in pre-training and post-training sessions, respectively, elicited by the flanker trials. The model for the N1 mean amplitude included the fixed effects of the training session, context, congruency, and their interactions, and also included the by-participant random slope for training session and context, and the by-item random intercept. As shown in Table 3, the

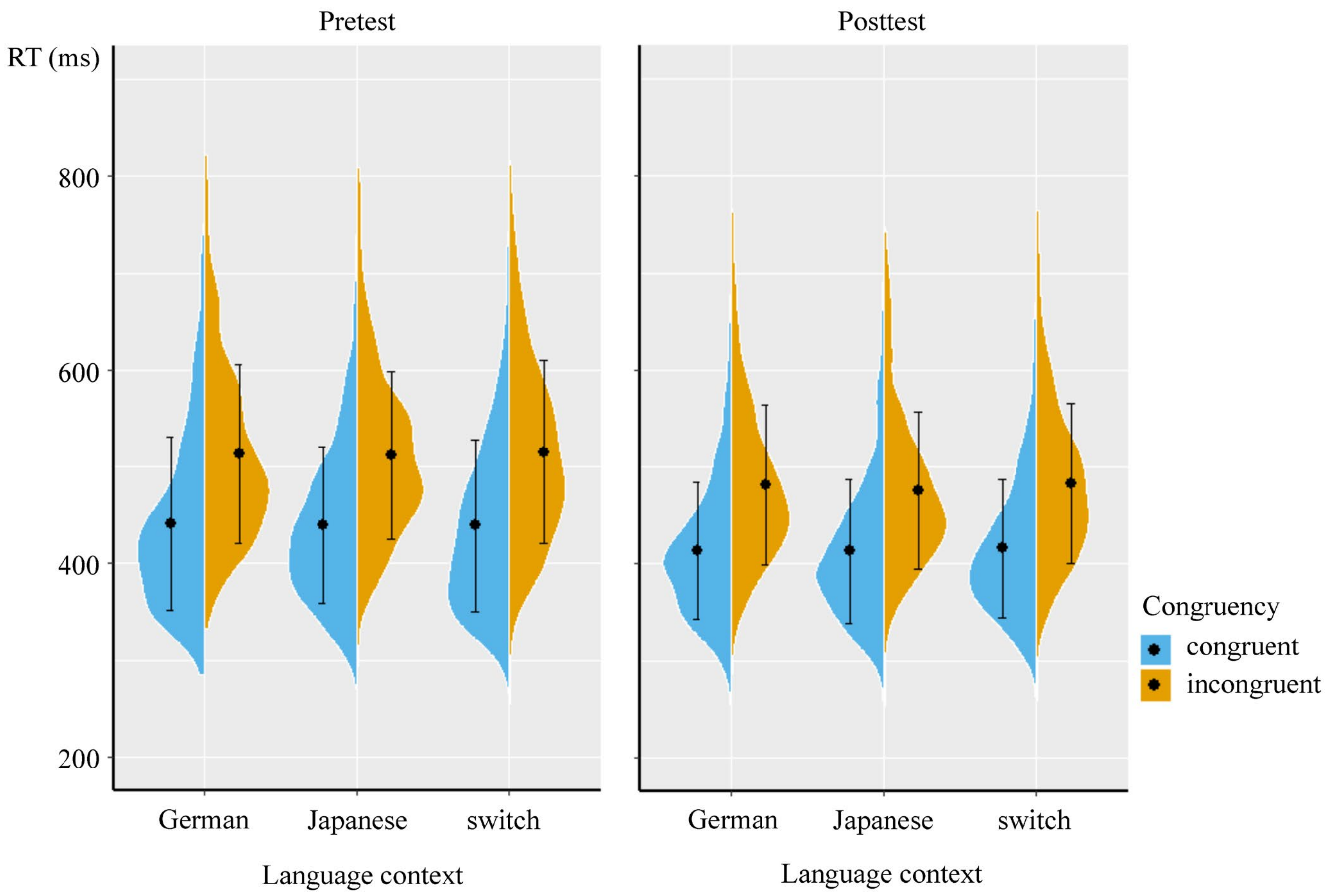

FIGURE 2 Split violin plots showing the RTs of the flanker task for each language context [left: German context; center: Japanese context; right: switch context] for each trial type (congruent and incongruent trial). The black dots represent the mean value and the vertical black lines represent the standard deviation

TABLE 2 Estimates of fixed effects for flanker RTs mixed-effects model

Fixed effects	Estimated	*SE*	*t*
(Intercept)	462.26	13.11	35.26***
Training session	−29.81	7.65	−3.89**
Congruency	66.89	1.50	44.62***
Context (non-switch vs. switch)	1.73	1.20	1.44
Context (German vs. Japanese)	−0.81	1.75	−0.46
Training session × Congruency	−8.19	2.22	−3.68***
Training session × Context (non-switch vs. switch)	3.09	2.36	1.31
Training session × Context (German vs. Japanese)	0.23	2.72	0.08
Congruency × Context (non-switch vs. switch)	2.27	2.43	0.93
Congruency × Context (German vs. Japanese)	0.59	3.29	0.18
Training session × Congruency × Context (non-switch vs. switch)	0.94	4.71	0.20
Training session × Congruency × Context (German vs. Japanese)	−2.84	5.45	−0.52

$^{**}p < .01$; $^{***}p < .001$.

incongruent flanker trials elicited larger N1 compared to congruent trials across all contexts, $t = -2.79$, $p = .005$, $\eta_p^2 = 0.20$. There was no effect of context or training session on the N1 time window.

3.2.2 | N2

The model for the N2 time window included the fixed effects of training session, context, congruency, and their interactions, along with the by-item random intercept and the by-participant random slope for training session, context, and congruency. Table 4 summarizes the fixed effects structure of the N2 model. First, across all contexts, incongruent flanker trials elicited larger N2 amplitudes than congruent trials ($t = -5.86$, $p < .001$, $\eta_p^2 = 0.67$). Additionally, the main effect of training session was significant ($t = -2.99$, $p = .008$, $\eta_p^2 = 0.34$), with larger N2 in the post-training session compared to the pre-training session. Importantly, context played a role in the flanker trials only during the post-training session, and not during the pre-training session, as demonstrated by the significant interaction between training session and context. Post-hoc analyses further revealed that in the post-training session, the congruent and incongruent flanker trials in switch context elicited larger N2 than non-switch context (Estimated $= -0.49$, $SE = 0.22$, $t = -2.17$, $p = .03$, $\eta_p^2 = 0.39$).

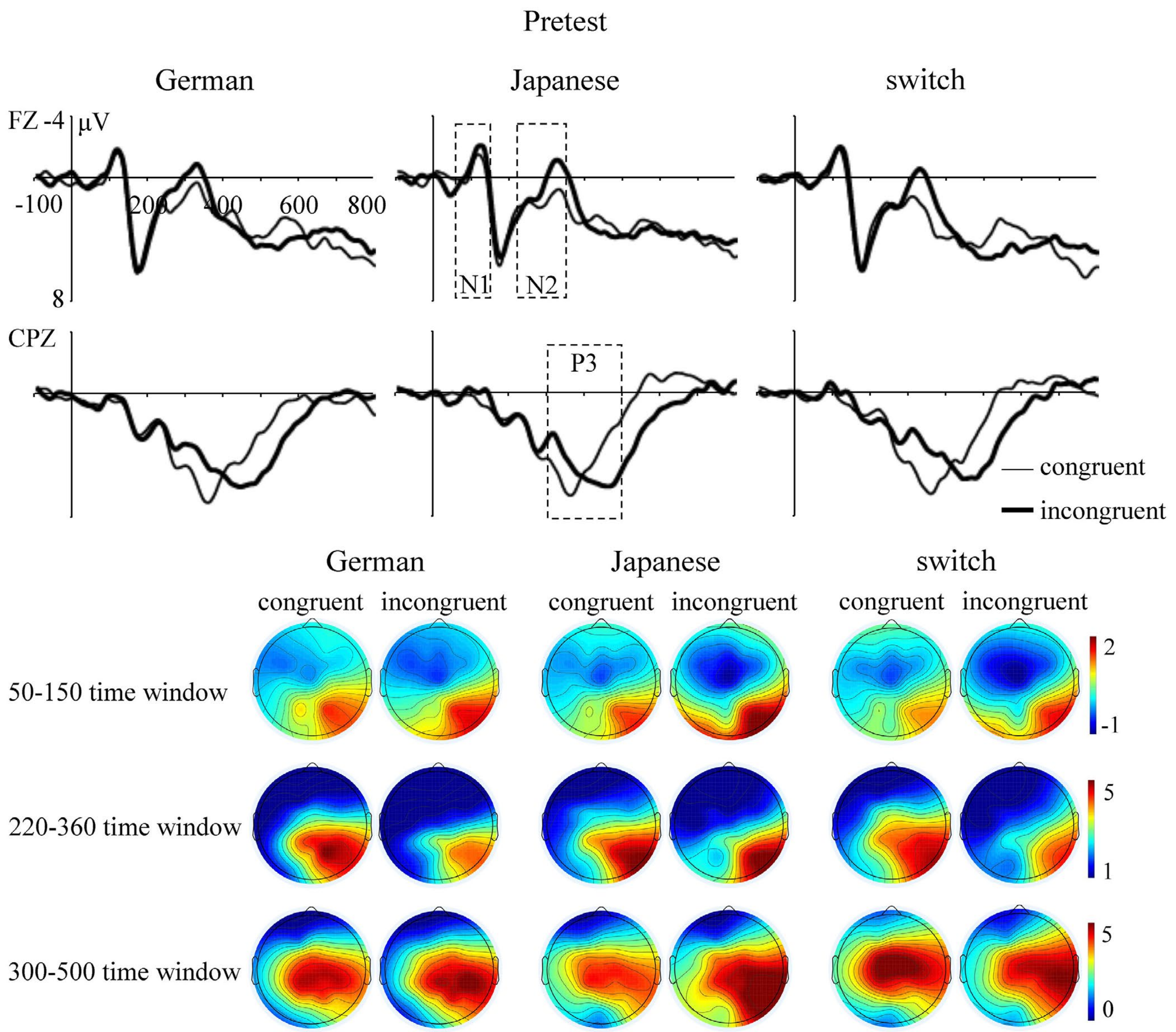

FIGURE 3 Pre-training session: Grand average waveform (upper panel) and topographic maps (lower panel) of congruent and incongruent flanker trials in German, Japanese, and switch contexts

3.2.3 | P3

The model for the P3 time window included the fixed effects of training session, context, congruency, and their interactions, as well as the by-item random intercept and the by-participant random slope for training session and congruency. As shown by Table 5, the three-way interaction for training session, context, and congruency was significant (t = 1.99, p < .05, η_p^2 = 0.33). The post-hoc analyses on the three-way interaction were conducted for pre-training session and post-training session separately. The results showed that there was no effect of context in the pre-training session. However, in the post-training session, the flanker effect in the Japanese context was smaller (switch vs. Japanese: t = −2.23, p = .03, η_p^2 = 0.21; German vs. Japanese: t = −2.15, p = .03, η_p^2 = 0.29) whereas no significant difference in the flanker effect between the other contexts (switch vs. German: t = 0.07, p = .94, η_p^2 < 0.01) was found.

4 | DISCUSSION

The present study examined the effects of language switching on domain-general executive control during the very beginning stages of learning new languages. By using a pre-/post-training design, Chinese speakers received language training in both German and Japanese and completed a flanker task

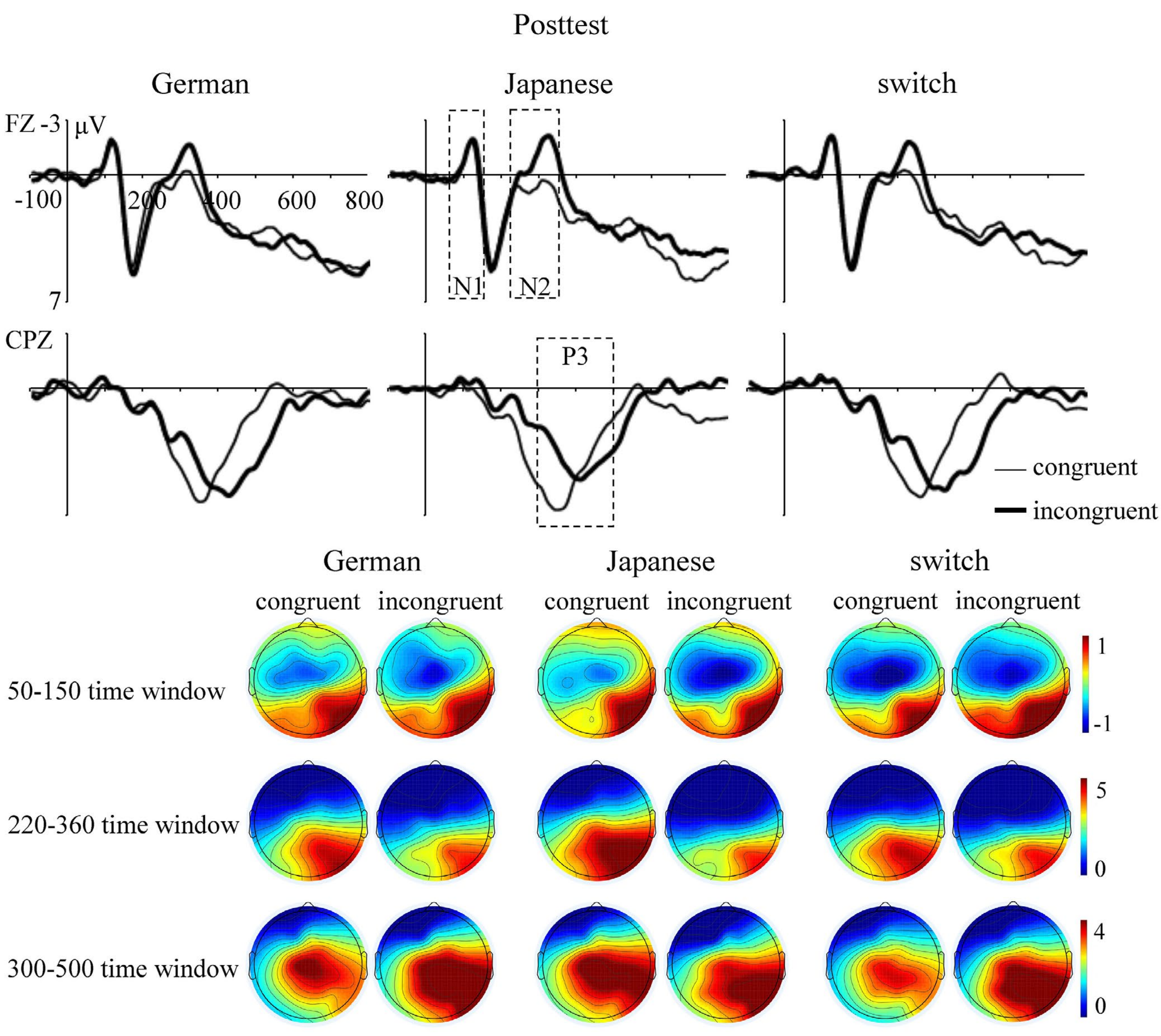

FIGURE 4 Post-training session: Grand average waveform (upper panel) and topographic maps (lower panel) of congruent and incongruent flanker trials in the German, Japanese, and switch contexts

TABLE 3 Estimates of fixed effects for mixed-effects model of N1 amplitude in flanker task

Fixed effects	Estimated	*SE*	*t*
(Intercept)	−0.62	0.36	−1.69
Training session	−0.19	0.28	−0.68
Congruency	−0.33	0.12	−2.79**
Context (non-switch vs. switch)	−0.22	0.16	−1.35
Context (German vs. Japanese)	−0.10	0.21	−0.49
Training session × Congruency	0.26	0.23	1.12
Training session × Context (non-switch vs. switch)	0.04	0.25	0.15
Training session × Context (German vs. Japanese)	0.09	0.29	0.31
Congruency × Context (non-switch vs. switch)	0.13	0.25	0.54
Congruency × Context (German vs. Japanese)	−0.25	0.29	−0.88
Training session × Congruency × Context (non-switch vs. switch)	0.50	0.50	1.00
Training session × Congruency × Context (German vs. Japanese)	0.27	0.58	0.46

$^{**}p < .01$.

in switch and non-switch contexts. Despite lacking behavioral evidence, the N2 and P3 amplitudes were affected by the switch manipulation in the post-training session but not in the pre-training session. These findings provided evidence for the language control effect of newly learned languages after training. Specifically, in the post-training session, flanker trials elicited larger N2 amplitudes in switch contexts compared to non-switch contexts, implying that more cognitive resources are allocated for conflict monitoring. Moreover, larger P3 amplitudes were observed during the switch context compared to the Japanese context, reflecting the involvement of conflict inhibition processes.

The present study contributes new insight to the relationship between bilingual language control and domain-general executive control by focusing on newly learned languages. Recent research reminds us that bilingualism should be understood as a phenomenon that is constantly shaped by a continuum of unique language experiences (DeLuca et al., 2019) which necessitate dynamic, adaptive language control processes (Green & Abutalebi, 2013). Prior to the present study, however, it was unknown as to whether controlling newly learned languages were related to executive control given that previous studies have mainly tested participants with some level of proficiency and experience with their languages (Jiao, Grundy, et al., 2020). The present study is among the very few (see also Liu et al., 2018) to examine these issues at the important stage in which learners are first exposed to a new language.

4.1 | The effect of controlling newly learned languages on executive control

The adaptive control hypothesis (Green & Abutalebi, 2013) articulates that different language contexts tap into distinct components of the executive control system. Grosjean's (2013) language-mode continuum framework proposes a continuum representing the different language situations and experiences of bilinguals. Both hypotheses emphasize the variable nature of bilingual language control and the involvement of the executive control system. The present study used EEG technology to explore the non-linguistic effects of controlling newly learned languages. Consistent with previous studies (Adler et al., 2020; Jiao, Grundy, et al., 2020), participants completed a flanker task in switch and non-switch language contexts in pre- and post-training sessions. We observed that in the pre-training session, in the switch context, language control did not affect participants' performance on the flanker task compared to the non-switch contexts. Thus, the results of the pre-training session function as a baseline for explaining patterns observed in the post-training session. In line with Jiao, Liu, et al. (2019), the absence of the context effect on the executive control system in the pre-training session implies that task difficulty (i.e., non-switch vs. switch context) and task design (i.e., the interleaved presentation of a flanker task and a language comprehension task) cannot explain the presence of context effect in the post-training session. If these two confounding factors indeed had affected executive control, to some extent, the context effect would have been detected in the pre-training session. This was not the case.

In the post-training session, we observed a language switching effect on executive control as evidenced by the larger N2 and P3 amplitudes elicited by flanker task in switch context compared to the non-switch contexts. The results of the post-training session provide evidence supporting the effects of controlling newly learned languages on domain-general executive control. Unlike non-switch contexts, in switch context, German and Japanese words are potential candidates. Thus, bilinguals must quickly identify target words, potentially switch to the other language, and then access the meaning. Furthermore, newly learned words from entirely new languages may recruit domain-general executive control procedures that resolve language conflicts, which in turn, affect the subsequent conflict resolution in the executive control domain (Adler et al., 2020; Hsu & Novick, 2016). Our findings offer further support to previous studies that provide evidence for the close

TABLE 4 Estimates of fixed effects for mixed-effects model of N2 amplitude in flanker task

Fixed effects	Estimated	*SE*	*t*
(Intercept)	1.35	0.74	1.82
Training session	−1.10	0.37	−2.99**
Congruency	−1.37	0.23	−5.86***
Context (non-switch vs. switch)	−0.04	0.22	−0.20
Context (German vs. Japanese)	0.004	0.31	0.01
Training session × Congruency	0.003	0.29	0.01
Training session × Context (non-switch vs. switch)	−0.87	0.31	−2.79**
Training session × Context (German vs. Japanese)	−0.23	0.36	−0.65
Congruency × Context (non-switch vs. switch)	0.07	0.31	0.22
Congruency × Context (German vs. Japanese)	−0.68	0.36	−1.88
Training session × Congruency × Context (non-switch vs. switch)	0.34	0.62	0.55
Training session × Congruency × Context (German vs. Japanese)	−0.77	0.72	−1.07

$^{**}p < .01$; $^{***}p < .001$.

relationship between language control at early stages of language learning and domain-general executive control (Kapa & Colombo, 2014; Liu et al., 2018).

4.2 | The dynamic nature of the relationship between bilingualism and executive control

Previous studies suggest that monitoring and inhibition are the two primary mechanisms that connect language control and executive control (Hilchey & Klein, 2011). For instance, the role of monitoring has been reflected by the overall improved performance of executive control. As in the present study, a study by Jiao, Liu, et al. (2020) used a cross-task-adaptation paradigm to examine the effects of switching between skilled languages on executive control and found larger N2 amplitudes across flanker trials. In line with these results, the present study also revealed larger N2 amplitudes across flanker trials after learning new languages. Taken together, these findings imply that in switch context, bilinguals rely more on early executive control processes, such as conflict monitoring and detection. However, regarding the differential findings between Jiao, Liu, et al. (2020) and the present study with respect to P3 amplitudes, we argue that it is a reflection of differences in cognitive effect between controlling skilled languages and controlling newly learned languages. Specifically, switching context between skilled languages elicited smaller P3 amplitudes in an executive control task, suggesting that less demand is placed on later control processes such as conflict resolution (Jiao, Liu, et al., 2020). However, in the present study, switching context between newly learned languages produced a larger flanker effect found in the P3 component, suggesting the demands placed on conflict inhibition.

TABLE 5 Estimates of fixed effects for mixed-effects model of P3 amplitude in flanker task

Fixed effects	Estimated	*SE*	*t*
(Intercept)	4.35	0.46	9.48***
Training session	−0.37	0.27	−1.33
Congruency	0.06	0.20	0.30
Context (non-switch vs. switch)	−0.22	0.13	−1.62
Context (German vs. Japanese)	−0.10	0.16	−0.62
Training session × Congruency	0.25	0.26	0.98
Training session × Context (non-switch vs. switch)	−0.14	0.27	−0.50
Training session × Context (German vs. Japanese)	−0.16	0.32	−0.50
Congruency × Context (non-switch vs. switch)	−0.06	0.27	−0.22
Congruency × Context (German vs. Japanese)	−0.36	0.32	−1.12
Training session × Congruency × Context (non-switch vs. switch)	1.10	0.55	1.99*
Training session × Congruency × Context (German vs. Japanese)	−1.13	0.64	−1.76

$^{*}p < .05$; $^{***}p < .001$.

One possible explanation for the larger flanker effect for newly learned languages is that controlling unskilled languages may exert more demand on cognitive control processes, necessitating a collaborative effort of both conflict monitoring and conflict inhibition processes. Considering recent discussions about the unreliability of difference scores elicited from executive control measures (Burgoyne

& Engle, 2020) such as the flanker task in the present study, future work should employ new methodological designs to investigate the role of inhibition mechanism in the cognitive effect of bilingualism.

Finally, we acknowledge a few limitations of the present study which are worth mentioning. Firstly, we trained only one group of participants and focused on these training effects in a post-training session. Despite having established their baseline performance based on the pre-training session, future studies may wish to consider including a control group. Moreover, the present study included a relatively small sample size. Subsequent studies examining the effects of language control of newly learned languages on executive control would benefit from testing larger simple sizes. Additionally, the present study and Jiao, Liu, et al. (2020) examined the effects of language control on executive control at different language proficiencies, but the two studies employed different bilingual groups. Based on the continuum viewpoint, future research should consider looking at bilinguals at different stages on the continuum throughout the language learning processes as they get more proficient.

5 | CONCLUSION

Consistent with the adaptive viewpoint proposed by Green and Abutalebi (2013), the effect of bilingual experience on executive control is related to the language learning/using experience of each individual. While many studies have examined language control and executive control with skilled languages, relatively little work has been done on the (very) initial stages of language learning. Used a training design and ERPs methodology, we investigated the relationship between the control of newly learned languages and executive control. Despite lacking evidence in the behavioral performance, the switch context elicited larger N2 and P3 in flanker task compared to the non-switch context, suggesting that controlling newly learned languages in the switch context may be related to the conflict monitoring and resolution processes in the executive control system. Our study contributes new insights into the relationship between bilingual language control and executive control and, in line with Green and Abutalebi's adaptive control hypothesis, supports the dynamic nature of bilingualism and their language experiences.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

AUTHOR CONTRIBUTIONS

Lu Jiao: Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Writing-original draft. **Cong Liu:** Conceptualization; Formal analysis; Methodology. **John W. Schwieter:** Writing-review & editing. **Baoguo Chen:** Conceptualization; Funding acquisition; Supervision; Writing-original draft; Writing-review & editing.

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