Journal of Neurolinguistics 51 (2019) 42–52

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

The influence of bilingual language experience on executive control: An ERPs study

Lu Jiao[a], Yuanyue Zhang[a], Patrick Plummer[b], Cong Liu[c], Baoguo Chen[a,*]

[a] Beijing Key Laboratory of Applied Experimental Psychology, Faculty of Psychology, Beijing Normal University, Beijing, 100875, China
[b] Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA, USA
[c] Guangdong Provincial Key Laboratory of Mental Health and Cognitive Science, and Center for Studies of Psychological Application, School of Psychology, South China Normal University, Guangzhou, 510631, China

ARTICLE INFO

Keywords:
Bilingualism
Executive control
L2 proficiency
Language switching frequency
Socioeconomic status

ABSTRACT

While some studies have examined the influence of bilingual language experience on executive control, few studies have looked at both bilingual experience and socioeconomic status (SES) together to see whether one, both, or an interaction exists when examining the executive control processing during a nonverbal conflict resolution task. To address this issue, the current study took advantage of event-related brain potentials (ERPs) as a group of bilinguals performed a nonverbal Stroop task for examining the influence of L2 proficiency and language switching frequency (bilingual language experience) on executive control. The electrophysiological results showed that L2 proficiency influenced the nonverbal Stroop task across congruency conditions and that the L2 proficiency effect was independent of individual's socioeconomic status. However, no evidence for language switching frequency effects on executive control were observed. These findings provided new electrophysiological evidence for the relationship between bilingual language experience and executive control, indicating the important role of L2 proficiency in executive control performance in bilinguals.

1. Introduction

The bilingual advantage over monolinguals on a range of executive control tasks has received a great deal of interest in the bilingualism literature (Bialystok, Craik, & Freedman, 2007; Costa, Hernández, & Sebastián-Gallés, 2008; see different opinion in Lehtonen et al., 2018; Paap, Johnson, & Sawi, 2015). However, there is very little research examining both effects of bilingual language experience and socioeconomic status (SES) together on executive control tasks, particularly lacking of electrophysiological evidence. Therefore, by making use of the ERP technique, the current study focuses on the influence of bilingual language experience (i.e., L2 proficiency and language switching) on executive control in a group of bilingual participants.

1.1. The previous studies of bilingual language experience on executive control

How language experience may have an influence on executive control in bilinguals is a question of interest. A well-accepted possibility for this potential influence originates from the nature of parallel activation of both languages when bilinguals plan speech, read words, and listen to speech in either of the two languages (Kroll, Dussias, Bice, & Perrotti, 2015; Marian & Spivey, 2003). Parallel

---

[*] Corresponding author. Faculty of Psychology, Beijing Normal University, No.19, Xin Jie KouWai St., Hai Dian District, Beijing, 100875, China.
E-mail address: Chenbg@bnu.edu.cn (B. Chen).

https://doi.org/10.1016/j.jneuroling.2018.12.002
Received 15 June 2018; Received in revised form 13 December 2018; Accepted 13 December 2018

activation of both languages means that bilingual language processing requires control mechanisms to resolve the competition between the two languages. This constant competition between two languages results in enhanced cognitive control that is not language-specific, but domain-general domain (Green, 1998). In particular, Green and Abutalebi (2013) proposed the Adaptive Control Hypothesis which emphasizes the way that language control cooperates with other cognitive control processes and changes across different contexts of language. According to this account, various bilingual language experiences (e.g., proficient or non-proficient in a second language) may lead to the recruitment of different control mechanisms to resolve language competition and exert adaptive influences on executive control. In addition, Language Mode framework assumes that a bilingual individual's position on the language-mode continuum (from monolingual-mode to bilingual-mode) changes the activation level of two languages and determines language control behavior (Grosjean, 2012). Therefore, to some extent, bilinguals with different language experience (e.g., proficient vs. less proficient bilinguals) will correspond to different positions on the language-mode continuum, characterized by particular language control mechanisms that have particular effects on executive control. We will begin by summarizing evidence from previous studies investigating the influence of bilingual language experience on executive control. In order to examine bilingual language experience, the current study will investigate potential effects of L2 proficiency and language switching.

L2 proficiency is a crucial parameter of bilingual language experience and has an important role on executive control. For example, Xie and Pisano (2018) selected three groups of unbalanced Chinese-English bilinguals to examine L2 proficiency effects on executive control tasks. In this study, 94 bilinguals with L2 proficiency levels rated as low, intermediate or high completed a Flanker task and the Wisconsin Card Sorting test (WCST). The results of the behavioral study showed that in the Flanker task, the highest L2 proficiency group performed significantly better than the lowest group in all three conditions (congruent, neutral, and incongruent), but there were no group differences in the flanker effect (i.e., the difference between incongruent and congruent trials). The overall response time in each condition of the Flanker task reflected conflict monitoring processes and their finding demonstrated the positive effect of L2 proficiency on conflict monitoring; whereas this study failed to find the L2 proficiency effect on inhibition reflected by flanker effect. Moreover, the WCST revealed no group differences, suggesting that there was no L2 proficiency effect on mental set shifting ability. The contributions of L2 proficiency to executive control among young adults has also been reported by Mishra, Hilchey, Singh, and Klein (2012). Mishra et al. (2012) examined two groups of Hindi-English bilinguals who differed in L2 proficiency. The participants were instructed to perform a target detection task which measured attention disengagement ability. The behavioral results showed that the high-proficiency bilingual group had faster overall reaction times than the low-proficiency bilingual group, suggesting that high L2 proficiency was associated with increased efficiency when disengaging attention from irrelevant information.

However, inconsistent effects of L2 proficiency have also been reported, revealing null effects of L2 proficiency on executive control performance (Dong & Xie, 2014; Rosselli, Ardila, Lalwani, & Vélez-Uribe, 2016). Dong and Xie (2014) used a large participant sample to examine the role of L2 proficiency and interpreting experience on executive control as measured by the Flanker task and WCST. The results showed no differences in Flanker task and WCST performance between groups differing in L2 proficiency, despite showing significant effects of interpreting experience on WCST performance.

Other studies have also reported an effect of language switching, another important parameter of bilingual language experience on executive control (Hartanto & Yang, 2016; Prior & Gollan, 2011; Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016). For example, Verreyt et al. (2016) compared behavioral performance on executive control tasks among three bilingual groups, i.e., unbalanced bilinguals (non-proficient and non-switching), balanced non-switching bilinguals (proficient but non-switching), and balanced switching bilinguals (proficient and switching). The results from the Flanker task and Simon arrow task showed that balanced switching bilinguals outperformed the other two groups with no group differences between unbalanced and balanced non-switching bilinguals. These findings suggest that rather than L2 proficiency, language switching played a crucial role in executive control performance for bilinguals.

However, not all studies in the bilingualism literature have offered support for the influence of language switching on executive control. For example, Jylkkä and colleagues conducted two experiments to examine the relationship between language switching experience measured by the bilingual switching questionnaire (BSWQ) and a range of executive control tasks, including Flanker, Simon, Spatial N-back task, and Number-letter task. The multiple regression analysis including BSWQ as predictor failed to find an effect of language switching on any of executive control tasks. (Jylkkä et al., 2017).

Importantly, when examining the effects of L2 proficiency and language switching frequency, individual differences in socioeconomic status (SES) must be taken into account, as SES is another important variable in bilingualism literature. For example, Morton and Harper (2007) found that controlling for SES differences may attenuate the cognitive benefits observed for bilinguals in comparison to monolinguals. Furthermore, when comparing monolingual and bilingual participants, Kirk, Fiala, Scott-Brown, and Kempe (2014) failed to replicate the bilingual advantage effect after controlling for individuals' SES background. However, Calvo and Bialystok conducted a study with a large participant sample to examine the effects of bilingual experience and SES together. Interestingly, even though higher-SES and bilingual experience both have a positive effect on executive control tasks, no interactions between bilingual experience and SES were found, indicating that the contributions measured by SES and bilingual experience were independent from one another (Calvo & Bialystok, 2014). Thus, it is necessary to consider the role of SES when examining the effects of bilingual experience on executive control.

In sum, some evidence suggests that L2 proficiency and language switching frequency may have an influence on executive control tasks. However, if bilingual language experience does have an effect on executive control tasks, which executive control skills are being influenced? In bilingualism research, the inconsistent findings for bilingual experience have mainly been focused on inhibition skill and monitoring skill in executive control.

On the one hand, some studies supported the idea that bilingual experience benefits interference inhibition skill as reflected by smaller interference effects in Flanker/Stroop/Simon tasks (i.e., the difference between incongruent trials and congruent/neutral trials) (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004). The bilingualism effect on inhibition may result from non-target language inhibition experience in bilinguals. Green (1998) proposed the inhibitory control model for bilingual language processing, emphasizing the key role of the inhibitory control mechanism used to inhibit a non-target language. Thus, bilinguals can apply these improved inhibitory control skills, which have been practiced extensive in bilingual processing, to nonverbal executive control tasks.

On the other hand, some studies showed a bilingual experience effect on both incongruent and congruent/neutral trials. For example, as mentioned above, Xie and Pisano (2018) revealed the L2 proficiency effect on each condition of the Flanker task and concluded that L2 proficiency contributed to conflict monitoring processes. Costa, Hernandez, Costa-Faidella, and Sebastian-Galles (2009) proposed that bilinguals need to constantly monitor and evaluate language context and social environment in order to communicate in the appropriate language, leading to better overall monitoring skill. This improved monitoring skill can be applied to nonverbal tasks. In the Stroop task, for example, bilinguals monitor and assess randomly presented trials, initiating the corresponding conflict control mechanisms. Thus, monitoring practice from bilingual experience would influence the overall performance of executive control tasks, because individuals have to monitor each trial.

1.2. The current study

Despite some studies in the bilingualism literature have investigated the effects of bilingual language experience on executive control, there is no consensus about these effects. Moreover, most of these studies focused on behavioral performance with no electrophysiological evidence of bilingual language experience on executive control. The ERP technique has the advantage of being a measure with high temporal resolution and may provide new insight into the effects of bilingual experience on executive control (Coderre & van Heuven, 2014; Heidlmayr, Hemforth, Moutier, & Isel, 2015; Moreno, Rodríguez-Fornells, & Laine, 2008). Therefore, the primary aim of the current study was taking advantage of electrophysiological measures to investigate the influence of bilingual language experience on executive control.

Specifically, the current study examined the effects of L2 proficiency and language switching frequency on executive control simultaneously. The current study also used a measure of socioeconomic status (SES) in order to assess the extent to which bilingual language experience was modulated by an individual's SES. In addition, the current study adopted a spatial Stroop task to measure inhibition and monitoring skill in executive control (Giezen, Blumenfeld, Shook, Marian, & Emmorey, 2015; Peterson et al., 2002). As in other interference control tasks (e.g., Flanker task), inhibition skill is reflected by the congruency effect, the difference between incongruent and congruent trials; and monitoring is reflected by the overall performance across congruent and incongruent trials. This nonverbal Stroop task has been commonly used in studies of bilingualism (e.g., see Experiment 2 in Liu et al., 2018). For example, Blumenfeld and Marian (2011) found a correlation between linguistic inhibition and nonlinguistic inhibition as measured by the Stroop task. The results indicated that the nonverbal, spatial Stroop task is a viable measure of executive control skill in bilinguals.

Electrophysiological data was recorded while performing the nonverbal Stroop task. Analysis of electrophysiological data focused on the N1, P2, N2, and P3 components, which previous studies have examined for executive control skills (Dong & Zhong, 2017; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009; see review by Grundy et al., 2017a,b). The N1 is a negative-going component related to early attentional processing (Beste, Saft, Andrich, Gold, & Falkenstein, 2008), with larger negative N1 amplitudes reflecting better early attentional processing (Dong & Zhong, 2017). The P2 component following N1 is also sensitive to attentional orientation (Shedden & Nordgaard, 2001) and stimulus categorization (Luck & Hillyard, 1994), with larger-amplitudes reflecting enhanced processing of relevant stimulus features. As opposed to the other three components, the P2 component is not typically examined in bilingualism literature, but is commonly examined in nonverbal interference control tasks (e.g., Johnstone et al., 2009). In a review of the neural correlates of executive control in bilingualism research, Grundy and colleagues point out that more L2 experience results in larger and earlier N2 and P3 components. The N2 component is a negative-going component that has a scalp distribution at fronto-central electrode sites (Folstein & Van Petten, 2008; Grundy, Chung-Fat-Yim, Friesen, Mak, & Bialystok, 2017), with larger N2 amplitudes signifying more resources being allocated to conflict processing. The P3 component is a reflection of stimulus categorization, with reduced amplitudes in conflict trials signifying more resource being allocated (Dong & Zhong, 2017; Kousaie & Phillips, 2012). For example, Dong and Zhong (2017) observed smaller P3 amplitudes signifying more attentional resource allocation.

Considering the complexity of bilingualism, the current study treated all bilingual background information (i.e., L2 proficiency, language switching frequency, and SES) as continuous variables. First, in regard to bilingual language experience, we hypothesized that both L2 proficiency and language switching frequency would influence executive control performance (at least in electrophysiological data). Given the findings of previous ERP studies comparing bilinguals and monolinguals, we expected any influence of bilingual language experience in the electrophysiological data to be observed in the N2 and P3 components (Grundy et al., 2017a,b). Second, based on previous behavioral studies examining the effects of L2 proficiency and language switching on executive control (e.g., Verreyt et al., 2016; Xie & Pisano, 2018), we assumed that any effects of bilingual language experience would be observed in both congruent and incongruent trials, providing new evidence for a monitoring account.

2. Methods

2.1. Participants

Thirty-four (24 female) Chinese (L1) – English (L2) bilinguals participated in the study for monetary compensation. They were all

Table 1
The characteristics of the participants.

	M	SD	Range
Age (years)	20.8	2.7	18–26
Age of L2 (years)	8.5	1.9	6–13
L2 proficiency	3.6	0.7	2.5–5.5
SES	17.0	4.7	8.0–24.0
BSWQ	2.6	0.4	1.8–3.4
BSWQ: L1S	3.2	0.7	2.0–5.0
BSWQ: L2S	2.4	0.5	1.7–3.7
BSWQ: CS	2.8	0.7	2.0–5.0
BSWQ: US	2.2	0.8	1.0–4.0

Note*:* Age of L2 represents the age of L2 acquisition of all bilingual participants; L2 proficiency, measured on a six-point Likert scale, is averaged by four self-reported scores in listening, speaking, reading, and writing; SES is calculated by summing up the score of each item in SES questionnaire with a five-point scale; BSWQ that was measured on a five-point scale represents the overall frequency of language switching across four aspects, and the following four items respectively represents the tendency switch to L1 (L1S), the tendency switch to L2 (L2S), contextual switch (CS), and unintended switch (US).

undergraduate students recruited from Beijing Normal University. All participants were born in China with no background of immigration or overseas education and Chinese as a native language. Participants were homogeneous in native language and culture. Moreover, all participants were sequential bilinguals, who were exposed to Chinese (L1) from birth and learned English (L2) at the mean age of 8.5 years old in a classroom setting. Participants had all passed the English examination to enter the university, and all had attended some courses in English, but there were considerable differences L2 proficiency and language switching (see Table 1). All participants were right handed, native Chinese speakers with normal or corrected-to-normal vision. None of the participants had neurological or psychological impairments, and none had used psychoactive medication. Data from five participants were eliminated prior to analysis: one due to low accuracy and four due to excessive EEG artifacts. Participants signed a consent form before the experiment. This study was approved by the Ethics Committee of the Faculty of Psychology, Beijing Normal University.

2.2. *Language background and socioeconomic status questionnaires*

All participants completed an L2 proficiency questionnaire, a bilingual switching questionnaire (BSWQ) intended to measure an individual's language use situation, and a socioeconomic status (SES) questionnaire intended to measure an individual's SES. We used a self-rated score on a Likert scale (1–6) in order to measure language proficiency in four separate aspects: listening, speaking, reading, and writing. This method of measuring L2 proficiency is widely used in bilingual research (Luo, Luk, & Bialystok, 2010). The indicator of L2 proficiency was the average score across the four aspects, wherein higher scores indicated higher L2 proficiency. The BSWQ was intended to measure the frequency of language switching in the bilingual participants. There were twelve items in the BSWQ and the questionnaire was rated on a five-point scale (Rodriguez-Fornells, Krämer, Lorenzo-Seva, Festman, & Münte, 2011). This questionnaire decomposed language switching into four constructs: L1S, the tendency to switch to L1 (Chinese); L2S, the tendency to switch to L2 (English); CS, an index of contextual language switching triggered by special situations; and US, an index of unintended language switching. Language switching frequency in the current study was measured by the scores across all items with higher scores indicating that more language switching occurs. Participants often switch between two languages in course or academic settings, particularly from L2 to L1. Following the method used by Shi and Shen (2007), the SES questionnaire consisted of questions about parental education attainment, current parental occupation, and family income. The items in the SES questionnaire were coded on a five-point scale: with parental education attainment ranging from 1 (unschooled) to 5 (bachelor and above), current parental occupation ranging from 1 (unemployed) to 5 (executive/professional), and family income ranging from 1 (very low) to 5 (very high). The sum of these scores was considered the SES indicator, ranging from 5 to 25 (Cheng & Wu, 2017; Shi & Shen, 2007). A summary of participant characteristics is provided in Table 1.

2.3. *Spatial stroop task*

The spatial Stroop task was used in the current study to measure the performance of domain-general executive control (Giezen et al., 2015; Peterson et al., 2002). In this task, one white arrow was presented on a black screen (either at the center, left side, or right side of the screen). Participants were instructed to press the left-hand response key when the arrow was pointing in the leftward-direction and to press the right-hand response key when the arrow was pointing in the rightward-direction. Thus, there were three types of experimental trials -baseline trials, congruent trials, and incongruent trials. Baseline trials consisted of a right or left facing arrow at the center of the screen. Congruent trails consisted of a right facing arrow on the right side of the screen or a left facing arrow on the left side of the screen. Incongruent trials consisted of a right facing arrow on the left side of the screen or a left facing arrow on the right side of the screen. The direction and location of the arrow was counterbalanced across baseline, congruent and incongruent trials.

Each trial began with the presentation of a fixation cross at the center of the screen for 500 ms, then an arrow was presented on the screen until participants responded to the stimulus (after 1200 ms the trial would time-out). After the stimulus, a blank screen appeared for 500 ms and then the next trial began. This task consisted of two blocks with 105 trials per block. The first buffer trial in each block was not analyzed, thus each block contained 52 congruent trials, 26 incongruent trials, and 26 baseline trials. The ratio of congruent to incongruent trials was 2:1. In comparison to the conventional Stroop task, the task in the current study contained baseline trials and more congruent trials in order to decrease the predictability of the next trial, making the current task more difficult. Additionally, only congruent trials and incongruent trials were analyzed because the two types of trials involved both location and direction information. The baseline trials in the nonverbal Stroop task reflect basic processes which may not involve conflict monitoring or resolution processes. Thus, it is not necessary to compare the time course of baseline trials to congruent/incongruent trials.

2.4. *Electrophysiological recordings*

Electrophysiological data were recorded from 64 Ag/AgCl electrodes placed according to the extended 10–20 positioning system. The signal was recorded with a 1 kHz sampling rate and referenced online to the right mastoid (M2). 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 refiltered offline with a 30 Hz low-pass, zero-phase shift digital filter. Off-line signal processing was carried out using Scan 4.3 (NeuroScan). Based on the record of VEOG and HEOG, eye blinks were corrected by using the function of a mathematical algorithm, a regression analysis associated with artifact averaging in order to produce a reliable and valid method to remove artifacts (Semlitsch, Anderer, Schuster, & Presslich, 1986). Continuous recordings were cut into epochs ranging from -100 to 600 ms relative to the onset of each stimulus. Baseline correction was performed in reference to pre-stimulus activity (-100 to 0 ms). Signals exceeding ± 75 μV in any given epoch were automatically discarded.

2.5. *Behavioral data analysis*

Considering the unequal ratio between congruent trials and incongruent trials, only the even trial numbers for congruent trials of each participant entered analysis. Data from the incorrect trials and response times exceeding M ± 3 SD were excluded. Response time and response accuracy were analyzed in R computing environment using linear mixed-effects models (LMMs) (lme 4 package, Baayen, Davidson, & Bates, 2008; Bates, Maechler, Bolker, & Walker, 2014). The main reason for using LMMs in favor of a traditional analysis is that LMMs allow examination of continuous variables that are based on subject-related differences (Baayen et al., 2008). A linear model was conducted for response time, whereas a logistic model was conducted for response accuracy because of the dependent variable's binominal distribution.

For each model, the fixed effects of theoretical interest were the continuous variables (L2 proficiency, language switching frequency, SES), congruency (congruent, incongruent), and the interaction for congruency with each continuous variable. As random effects, each model included a random intercept for subjects and trials. The congruency variable was coded using mean-centered contrast-coding (i.e., congruent = -0.5, incongruent = 0.5). All continuous variables were centered by z-score transformation of raw scores to reduce collinearity (de Bruin, Samuel, & Duñabeitia, 2018; Tzeng, Hsu, Huang, & Lee, 2017). In order to test for multicollinearity between continuous predictors, each model included in the current study was checked by Variance Inflation Factors (VIFs), and all were below 2.

2.6. *Event-related brain potential analysis*

The ERP analysis included four components on the basis of our theoretical interests. The time window selection for each component was based on a combination of our data and previous studies examining executive control tasks (Dong & Zhong, 2017; Johnstone et al., 2009). The LMMs were performed on single-trial amplitudes in the following time-windows: 150–190 ms for N1, 210–270 ms for P2, and 270–320 ms for N2. For the P3 component, we selected different time-windows for congruent (300–400 ms) and incongruent trials (380–480 ms) in accordance with their peak latency, because there was a significant difference between the peak latency of congruent trials (M = 351 ms) and incongruent trials (M = 432 ms) ($t = -7.07$, $p < 0.001$). A Greenhouse-Geisser correction was performed where applicable. The electrode sites were selected by visual inspection of the current data and reference to previous studies of nonverbal executive control. For N1, P2, and N2, the following electrode sites were chosen: F1, FZ, F2, FC1, FCZ, FC2, C1, CZ, C2 (Dong & Zhong, 2017; Folstein & Van Petten, 2008; Grundy, Chung-Fat-Yim, et al., 2017); the selected electrode sites for P3 included C1, CZ, C2, CP1, CPZ, CP2, P1, PZ, P2 (Wu & Thierry, 2013). The fixed effects and random effects included in the LMM for each component were the same as those in the behavioral data.

3. Results

3.1. *Behavioral results*

Table 2 shows the mean response time (RT) and mean accuracy of congruent trials and incongruent trials in the spatial Stroop task. Following the analysis procedure for behavioral data, we fitted a mixed-effects model for RT. We included random slopes and intercepts for both participants and trials as random effects for congruency. No other factor was included in the random effects

Table 2

Mean RT (ms) and accuracy (%) of congruent and incongruent trials in the spatial Stroop task with SD.

	RT		Accuracy	
	Mean	SD	Mean	SD
Congruent	437	88.06	98	15.48
Incongruent	493	75.54	86	34.84

structure in the fitted model because they did not improve model fit (p's > 0.05) (see Hsu & Novick, 2016; Huang, Zheng, Meng, & Snedeker, 2013). Table 3 shows the results of LMM analysis for RT and accuracy. The LMM analysis on RT showed significant congruency and SES effects, but no significant effects of L2 proficiency and language switching frequency. As shown by the mean in Table 2, the significant congruency effect indicates that bilinguals responded faster in congruent trials (M = 436.79 ms) than incongruent trials (M = 492.49 ms), in line with the conventional Stroop effect. Fig. 1 shows the relationship between SES and executive control performance in the spatial Stroop task, indicating that as socioeconomic status increases, response time decreased.

For accuracy, the logistic mixed-effects model was fitted with the same fixed and random effects structure as the linear mixed-effects model for RT. As Table 3 shows, only the congruency effect reached significance, indicating higher accuracy in congruent trials (M = 97.55%) than incongruent trials (M = 85.88%). There were no other significant effects or interactions on accuracy.

3.2. ERP results

Fig. 2 shows the grand-averaged event-related potential waveforms elicited by congruent trials and incongruent trials. The LMM analysis of the ERP data used the same procedure as the behavioral analysis. The linear mixed-effects models for each component included the three continuous variables, congruency, and the interaction of congruency with each continuous variable as fixed effects, with by-participant and by-trial random intercepts as random effects. The results from the LMM analysis on the N1 time-window (150–190 ms) and P2 time-window (210–270 ms) are presented in Table 4. The results for N1 and P2 showed there was no difference between the cognitive processes involved in congruent trials and incongruent trials. The absence of a significant interaction suggests that for N1 and P2 components, neither congruent nor incongruent cognitive processes were influenced by individuals' language background or socioeconomic status.

Table 5 shows the results from the LMM analysis on N2 (270–320 ms) and P3 (congruent trials in 300–400 ms, incongruent trials in 380–480 ms). The LMM analysis for N2 revealed significant effects of congruency and L2 proficiency, but no effects of language switching frequency or SES. Fig. 3 shows the relationship between L2 proficiency and N2 amplitude (left panel), indicating that larger N2 amplitudes corresponded with higher L2 proficiency. In order to examine whether the influence of L2 proficiency was modulated by an individual's SES level, we examined the interaction between L2 proficiency and SES variables. First, based on the current model used to analyze ERP data, we built a more complex model by adding the interaction of L2 proficiency and SES as a fixed effect. Subsequently, the significance of the interaction of L2 proficiency and SES was assessed by model comparison in R environment. The results showed there was no significant difference between the two models ($\chi^2 = 0.21$, $df = 1$, $p = 0.65$), suggesting that the L2 proficiency effect on Stroop task was not modulated by SES.

Table 5 shows the results on the P3 component, where there was a marginally significant effect of congruency ($t = -1.87$, $p = 0.06$). Meanwhile, L2 proficiency also exerted a significant effect on the amplitude of the P3 component ($t = -2.34$, $p < 0.05$). Larger P3 amplitudes were elicited by higher L2 proficiency (see Fig. 3, right panel), but no effect of language switching frequency or SES was observed. Following the aforementioned procedure of model comparison for examining the interaction between L2 proficiency and SES, result for the P3 component also showed there were no significant difference between the model with the interaction between L2 proficiency and SES and the model without this interaction ($\chi^2 = 0.78$, $df = 1$, $p = 0.38$), suggesting the L2 proficiency

Table 3

Linear mixed model (LMM) estimates of fixed effects for RT and accuracy.

	RT			Accuracy		
	estimate	SE	*t*	estimate	SE	*z*
Intercept	465.61	8.03	57.94	3.09	0.16	19.63
Congruency	**54.61**	**6.52**	**8.36*****	**−1.63**	**0.37**	**−4.48*****
BSWQ	5.99	7.65	0.78	0.05	0.11	0.47
L2 proficiency	−2.13	7.69	−0.27	0.07	0.11	0.62
SES	**−20.85**	**7.80**	**−2.67***	0.07	0.12	0.60
Congruency: BSWQ	−1.06	4.24	−0.25	0.07	0.28	0.25
Congruency: L2 proficiency	1.05	4.25	0.24	0.08	0.28	0.27
Congruency: SES	−1.00	4.35	−0.23	−0.42	0.29	−1.46

Note: The bilingual switching questionnaire (BSWQ) was used as the measure of language switching frequency. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

The bold items represent the significant effects on nonverbal Stroop task.

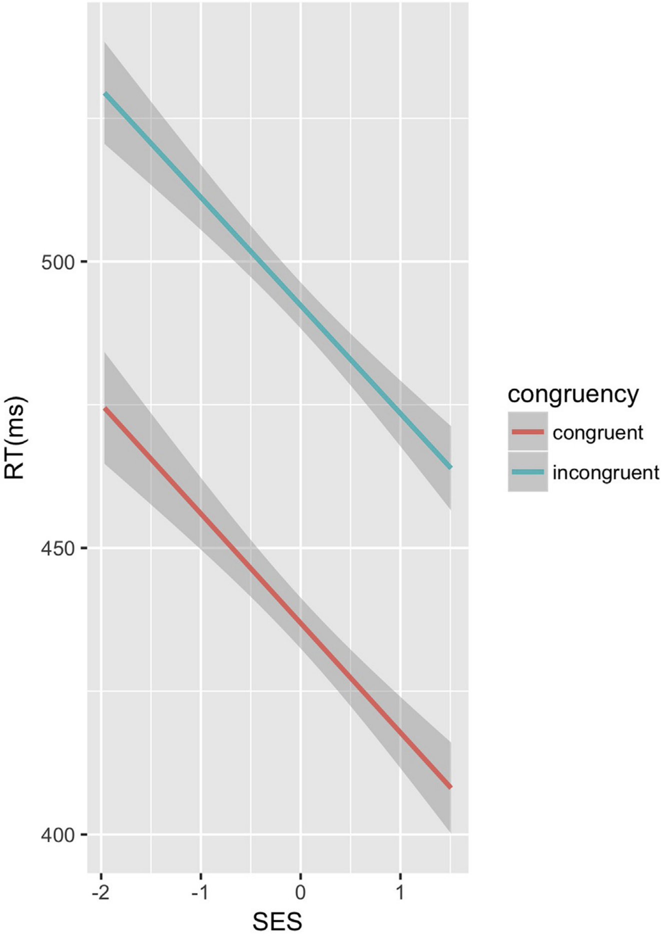

Fig. 1. RT (ms) as a function of trial condition and socioeconomic status (centered by *z*-score transformation of raw scores). Error bands show 95% confidence intervals. Higher SES scores corresponded to faster behavioral responses.

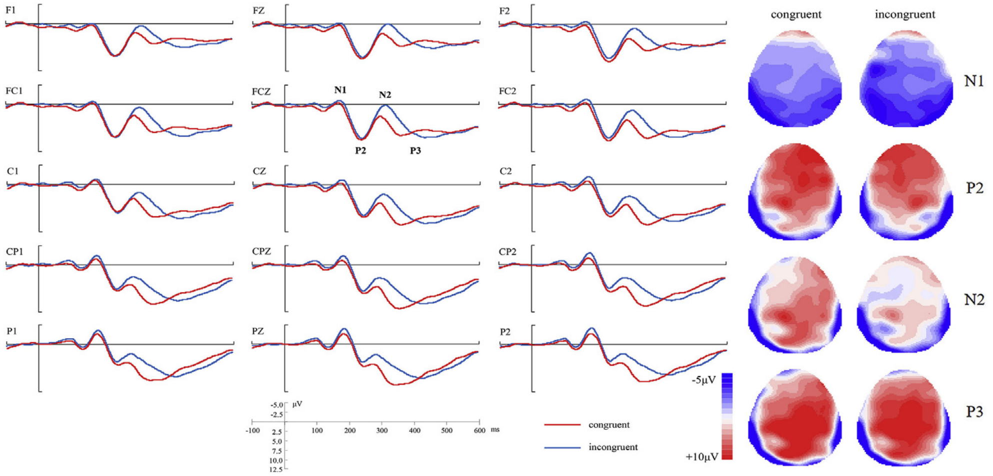

Fig. 2. Grand average waveforms (left panel) and topographic maps (right panel) of congruent and incongruent trials in spatial Stroop task.

effect on the nonverbal, spatial Stroop task was independent of SES. In sum, on the basis of electrophysiological data, neither L2 proficiency nor language switching frequency has an influence on N1 and P2 components. However, despite observing no effects of language switching, L2 proficiency did have an effect on the N2 and P3 components, in which higher L2 proficiency was associated

Table 4
Linear mixed model (LMM) estimates of fixed effects for the amplitudes of N1 and P2 components.

	N1			P2		
	estimate	SE	*t*	estimate	SE	*t*
Intercept	−0.46	0.59	−0.77	7.32	0.71	10.29
Congruency	−0.23	0.40	−0.58	−0.13	0.41	−0.30
BSWQ	−0.26	0.61	−0.42	0.16	0.74	0.22
L2 proficiency	0.46	0.62	0.74	0.31	0.74	0.41
SES	0.05	0.63	0.08	0.77	0.75	1.03
Congruency: BSWQ	0.12	0.41	0.29	0.32	0.43	0.76
Congruency: L2 proficiency	−0.13	0.41	−0.31	−0.43	0.43	−1.01
Congruency: SES	−0.05	0.42	−0.11	−0.06	0.44	−0.14

Note: The bilingual switching questionnaire (BSWQ) was used as the measure of language switching frequency. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 5
Linear mixed model (LMM) estimates of fixed effects for the amplitudes of N2 and P3 components.

	N2			P3		
	estimate	SE	*t*	estimate	SE	*t*
Intercept	3.63	0.56	6.43	9.07	0.66	13.79
Congruency	**−2.30**	**0.43**	**−5.30*****	**−0.74**	**0.40**	**−1.87**$^{+}$
BSWQ	0.50	0.58	0.86	−0.01	0.68	−0.02
L2 proficiency	**1.63**	**0.59**	**2.77****	**1.61**	**0.69**	**2.34***
SES	0.88	0.60	1.48	1.12	0.69	1.61
Condition: BSWQ	0.03	0.45	0.08	−0.40	0.41	−0.98
Condition: L2 proficiency	0.07	0.45	0.16	−0.49	0.41	−1.91
Condition: SES	−0.69	0.46	−1.49	0.40	0.43	0.95

Note: The bilingual switching questionnaire (BSWQ) was used as the measure of language switching frequency. $+p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
The bold items represent the significant effects on nonverbal Stroop task.

with larger N2/P3 amplitudes. Importantly, the L2 proficiency effect was shown to be independent of an individual's SES.

4. Discussion

Using the ERP technique, the current study investigated both bilingual language experience, measured by L2 proficiency and language switching frequency, and SES together to see whether one, both, or an interaction occurred on bilinguals' executive control performance. The following results were observed: (1) the electrophysiological data revealed that L2 proficiency had an influence on the nonverbal Stroop task across congruency conditions (i.e., N2 and P3 components), and this influence was independent of SES; (2) neither behavioral data nor electrophysiological data found an influence of language switching frequency on the nonverbal Stroop task. These findings are discussed in the sections below.

In the electrophysiological results of the current study, L2 proficiency exerted a positive influence on N2 and P3 components, whereas no influence on N1 or P2 components was observed. One potential reason for the pattern of results showing a lack of L2 proficiency effects on N1/P2 components might be that these components measured early attentional orientation and perceptual detection of a stimulus, processes less dependent on executive control skills (Blackburn, 2013; Polich, 2007; Yeung, Botvinick, & Cohen, 2004). For the N2 and P3 components, the effect of L2 proficiency observed on both congruent and incongruent trials of the nonverbal Stroop task reflected monitoring skill in executive control (Struys, Woumans, Nour, Kepinska, & Van den Noort, 2018; Xie & Pisano, 2018).

The effect of L2 proficiency on monitoring skill is related to the Adaptive Control Hypothesis (Green & Abutalebi, 2013). This hypothesis proposes that different levels of cognitive demand are imposed by different interactional contexts of conversation for bilinguals. These demands across contexts adaptively alter the way in which the two languages are controlled and made to cooperate with other skills. In the current study, because of differences in L2 proficiency, the demands placed on the executive control system by the task resulted in different influences on executive control performance. Specifically, the activation status of the two languages would be more comparable in higher proficiency bilinguals when compared to lower proficiency bilinguals, and this higher activation level of the non-target language would induce more interference then. As a result, bilinguals have to continuously monitor their current environment in order to communicate in the target language. Thus, when high-proficiency bilinguals performed nonverbal tasks that mix different types of trials (e.g., congruent and incongruent trial), they can monitor and quickly evaluate the trial type, in parallel with the continuous monitoring behavior for two languages. Importantly, every type of trial would be assessed by the type of monitoring control that was influenced by L2 proficiency, rather than only conflicting trials.

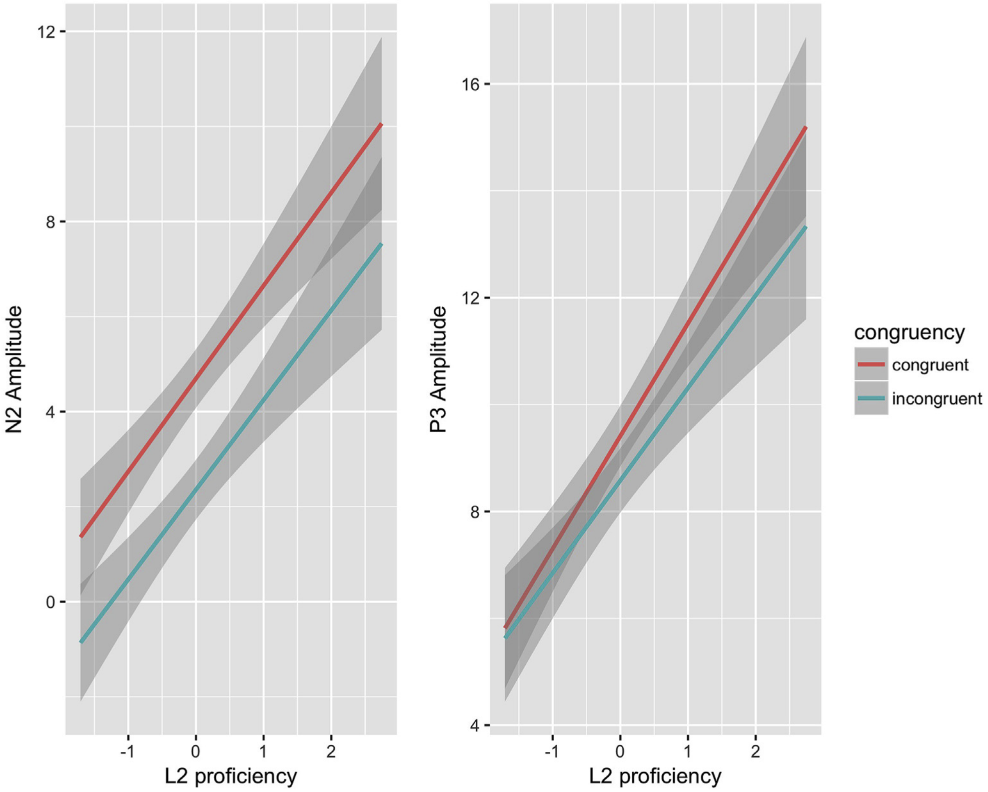

Fig. 3. Mean amplitude (left panel for N2; right panel for P3) as a function of trial condition and L2 proficiency (centered-by *z*-score transformation of raw scores). Error band shows 95% confidence intervals. Higher L2 proficiency corresponded to lager N2 and P3 amplitudes.

Consistent with our finding about the effect of L2 proficiency on monitoring, Costa et al. (2009) also demonstrated a bilingual benefit effect on a high demand monitoring task. This study included two versions of a Flanker task with different monitoring demands and revealed that when compared with monolinguals, bilinguals performed better under high demand monitoring conditions, but no bilingual effect under low demand monitoring conditions. Moreover, Xie and Pisano (2018) made use of a multiple stepwise regression analysis and found that L2 proficiency was a predictor for behavioral performance on all conditions of the Flanker task (i.e., congruent, incongruent, and neutral condition).

Importantly, the L2 proficiency effects on N2 and P3 were consistent with previous electrophysiological studies showing larger N2/P3 amplitudes in bilinguals relative to monolinguals (Grundy et al., 2017a,b). Given that larger N2 amplitudes signify more resources being deployed, the positive association between L2 proficiency and N2 amplitude revealed that the higher proficiency bilinguals were more efficient in monitoring different types of trials in comparison with lower proficiency bilinguals. The lack of an L2 proficiency effect on behavioral performance did not meet with our expectations. However, this may be less surprising when considering that the RT indicator reflects all processing stages from stimulus presentation to behavioral response. The high temporal resolution ERP indicators achieve real time brain activity and examine the different sub-processes of executive control. This advantage of the ERP technique was our main motivation for investigating the influence of bilingual language experience on different processing stages of executive control.

Consistent with the current study, Moreno and colleagues conducted one ERP study for comparing the nonverbal task performance among bilingual, musician, and control group. The researchers asked young adults to perform a nonverbal go/no-go task. Electrophysiological data analysis showed that compared with the musician and control groups (without musical or bilingual experience), the bilingual group elicited larger N2 and late positivity waves (Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014). Importantly, there was no difference shown by behavioral indicators. Based on the comparison between the control and bilingual groups in electrophysiological findings, the researchers concluded that bilinguals performed better on conflict detection and resource allocation during conflict resolution.

Kousaie and Phillips (2012) found that incongruent trials elicited smaller P3 amplitudes in a Stroop task, suggesting that the smaller P3 amplitude reflected more resource allocation to conflict processing. Combined with our findings, the relationship between L2 proficiency and P3 amplitude demonstrates that bilinguals with high L2 proficiency need fewer conflict processing resources at the P3 component. Thus, the integral findings for the N2 and P3 components demonstrate that with the increasing of L2 proficiency, bilinguals showed larger N2 amplitude signifying more resource being deployed in this stage, and larger P3 amplitude signifying less resource being needed to resolve conflict.

With regard to the role of language switching frequency, inconsistent with our expectation, neither behavioral data nor electrophysiological data in the current study showed an influence of language switching frequency on the nonverbal Stroop task. Based on the Adaptive Control Hypothesis viewpoint, experience in switching between two languages would adaptively influence the specific skills of executive control (e.g., set-switching skill). One possibility for not observing language switching effects is that the nonverbal Stroop task in the current study failed to measure individual's shifting ability. In reviewing previous studies showing language switching effects, it is important to note that most of these studies employed a nonverbal task relevant to set-switching skill (e.g., color-shape shifting task) (Hartanto & Yang, 2016; Prior & Gollan, 2011). For example, Hartanto and Yang (2016) compared two groups of proficient bilinguals with different language switching frequencies in task-switching performance and observed that high-frequency switchers showed smaller task-switching costs than low-frequency switchers.

Similar to the nonverbal Stroop task used in the current study, Verreyt et al. (2016) used the Flanker and Simon tasks to compare executive control performance of unbalanced bilinguals, balanced non-switching bilinguals, and balanced switching bilinguals. The results showed better performance by balanced switching bilinguals and demonstrated that language switching is the key experience for bilingual executive control performance because of the matched L2 proficiencies across all participant groups. These inconsistent findings examining the language switching effect on interference control and task-switching suggest that there is no consensus on the effect of language switching (e.g., Hartanto & Yang, 2016; Jylkkä et al., 2017; Paap & Greenberg, 2013; Prior & Gollan, 2011). Another possible reason for the absence of language switching effects is that the participants in our study live in their native language environment. Participants reported that they mainly switch languages in the classroom or other academic environments. Thus, compared with bilingual individuals living in a dual-language environment, language switching variability in the current study may be too restricted to reveal the influence of language switching on executive control. Thus, the question of whether language switching influences executive control requires further examination on bilinguals with higher frequency language switching or bilinguals with a range of different switching frequencies.

Except for the effect of L2 proficiency and language switching, the current study examined the effect of L2 proficiency, language switching and SES together. In line with previous studies, there was a positive effect of SES on performance on the nonverbal Stroop task in behavioral data (e.g., Xie & Pisano, 2018), namely individuals in higher SES level showed faster behavioral response in nonverbal Stroop task. Importantly, there was no significant interaction of L2 proficiency and SES (for results of the N2, P3 components), indicating that L2 proficiency had an influence on executive control across different levels of SES.

5. Conclusion

Using ERP technology, the current study provided electrophysiological evidence for the influence of bilingual language experience on executive control. Based on electrophysiological data, despite the absence of a difference in behavioral results, L2 proficiency had an influence on a nonverbal Stroop task across congruency conditions, and the effect of L2 proficiency was independent of SES level. The results showing the L2 proficiency effect across congruency conditions suggest that when performing a nonverbal task that mixes different types of trials, bilinguals with relatively high L2 proficiency could more efficiently monitor and identify the target trial type as they constantly monitored different languages. However, the current study failed to find the influence of language switching frequency on a nonverbal Stroop task. Overall, the current study provided new electrophysiological evidence for the relationship between language experience and executive control in bilinguals.

Disclosure statement

No potential conflict of interest was reported by the authors.

Acknowledgment

This work was supported by funding from Beijing Education Science Planning of 13th Five-Year (CADA17077) for Baoguo Chen.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jneuroling.2018.12.002.

References

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.

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.

Beste, C., Saft, C., Andrich, J., Gold, R., & Falkenstein, M. (2008). Stimulus-response compatibility in huntington's disease: A cognitive-neurophysiological analysis. *Journal of Neurophysiology, 99*(3), 1213–1223.

Bialystok, E., Craik, F. I., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia, 45*(2), 459–464.

Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging, 19*(2), 290–303.

Blackburn, A. M. (2013). *A study of the relationship between code switching and the bilingual advantage: Evidence that language use modulates neural indices of language processing and cognitive control.* The University of Texas at San Antonio.

Blumenfeld, H. K., & Marian, V. (2011). Bilingualism influences inhibitory control in auditory comprehension. *Cognition, 118*(2), 245–257.

de Bruin, A., Samuel, A. G., & Duñabeitia, J. A. (2018). Voluntary language switching: When and why do bilinguals switch between their languages? *Journal of Memory* *and Language, 103*, 28–43.

Calvo, A., & Bialystok, E. (2014). Independent effects of bilingualism and socioeconomic status on language ability and executive functioning. *Cognition, 130*(3), 278–288.

Cheng, Y., & Wu, X. (2017). The relationship between SES and reading comprehension in Chinese: A mediation model. *Frontiers in Psychology, 8*, 672.

Coderre, E. L., & van Heuven, W. J. (2014). Electrophysiological explorations of the bilingual advantage: Evidence from a Stroop task. *PLoS One, 9*(7).

Costa, A., Hernandez, M., Costa-Faidella, J., & Sebastian-Galles, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition, 113*(2), 135–149.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition, 106*(1), 59–86.

Dong, Y., & Xie, Z. (2014). Contributions of second language proficiency and interpreting experience to cognitive control differences among young adult bilinguals. *Journal of Cognitive Psychology, 26*(5), 506–519.

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.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*(1), 152–170.

Giezen, M. R., Blumenfeld, H. K., Shook, A., Marian, V., & Emmorey, K. (2015). Parallel language activation and inhibitory control in bimodal bilinguals. *Cognition, 141*, 9–25.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*(2), 67–81.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology, 25*(5), 515–530.

Grosjean, F. (2012). *Bilingual and monolingual language modes.* The encyclopedia of applied linguistics1–9.

Grundy, J. G., Anderson, J. A., & Bialystok, E. (2017a). Neural correlates of cognitive processing in monolinguals and bilinguals. *Annals of the New York Academy of Sciences, 1396*(1), 183–201.

Grundy, J. G., Chung-Fat-Yim, A., Friesen, D. C., Mak, L., & Bialystok, E. (2017b). Sequential congruency effects reveal differences in disengagement of attention for monolingual and bilingual young adults. *Cognition, 163*, 42–55.

Hartanto, A., & Yang, H. (2016). Disparate bilingual experiences modulate task-switching advantages: A diffusion-model analysis of the effects of interactional context on switch costs. *Cognition, 150*, 10–19.

Heidlmayr, K., Hemforth, B., Moutier, S., & Isel, F. (2015). Neurodynamics of executive control processes in bilinguals: Evidence from ERP and source reconstruction analyses. *Frontiers in Psychology, 6*, 821.

Hsu, N. S., & Novick, J. M. (2016). Dynamic engagement of cognitive control modulates recovery from misinterpretation during real-time language processing. *Psychological Science, 27*(4), 572–582.

Huang, Y. T., Zheng, X., Meng, X., & Snedeker, J. (2013). Children's assignment of grammatical roles in the online processing of Mandarin passive sentences. *Journal of Memory and Language, 69*(4), 589–606.

Johnstone, S. J., Barry, R. J., Markovska, V., Dimoska, A., & Clarke, A. R. (2009). Response inhibition and interference control in children with AD/HD: A visual ERP investigation. *International Journal of Psychophysiology, 72*(2), 145–153.

Jylkkä, J., Soveri, A., Wahlström, J., Lehtonen, M., Rodríguez-Fornells, A., & Laine, M. (2017). Relationship between language switching experience and executive functions in bilinguals: An Internet-based study. *Journal of Cognitive Psychology, 29*(4), 404–419.

Kirk, N. W., Fiala, L., Scott-Brown, K. C., & Kempe, V. (2014). No evidence for reduced Simon cost in elderly bilinguals and bidialectals. *Journal of Cognitive Psychology, 26*(6), 640–648.

Kousaie, S., & Phillips, N. A. (2012). Conflict monitoring and resolution: Are two languages better than one? Evidence from reaction time and event-related brain potentials. *Brain Research, 1446*, 71–90.

Kroll, J. F., Dussias, P. E., Bice, K., & Perrotti, L. (2015). Bilingualism, mind, and brain. *Annual Review of Linguistics, 1*(1), 377–394.

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.

Liu, C., Jiao, L., Wang, Z., Wang, M., Wang, R., & Wu, Y. J. (2018). Symmetries of bilingual language switch costs in conflicting versus non-conflicting contexts. *Bilingualism: Language and Cognition,* 1–13.

Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology, 31*(3), 291–308.

Luo, L., Luk, G., & Bialystok, E. (2010). Effect of language proficiency and executive control on verbal fluency performance in bilinguals. *Cognition, 114*(1), 29–41.

Marian, V., & Spivey, M. (2003). Competing activation in bilingual language processing: Within-and between-language competition. *Bilingualism: Language and Cognition, 6*(2), 97–115.

Mishra, R. K., Hilchey, M. D., Singh, N., & Klein, R. M. (2012). On the time course of exogenous cueing effects in bilinguals: Higher proficiency in a second language is associated with more rapid endogenous disengagement. *The Quarterly Journal of Experimental Psychology, 65*(8), 1502–1510.

Moreno, E. M., Rodríguez-Fornells, A., & Laine, M. (2008). Event-related potentials (ERPs) in the study of bilingual language processing. *Journal of Neurolinguistics, 21*(6), 477–508.

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).

Morton, J. B., & Harper, S. N. (2007). What did Simon say? Revisiting the bilingual advantage. *Developmental Science, 10*(6), 719–726.

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.

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. *Cortex, 69*, 265–278.

Peterson, B. S., Kane, M. J., Alexander, G. M., Lacadie, C., Skudlarski, P., Leung, H.-C., ... Gore, J. C. (2002). An event-related functional MRI study comparing interference effects in the Simon and Stroop tasks. *Cognitive Brain Research, 13*(3), 427–440.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*(10), 2128–2148.

Prior, A., & Gollan, T. H. (2011). Good language-switchers are good task-switchers: Evidence from Spanish-English and Mandarin-English bilinguals. *Journal of the International Neuropsychological Society, 17*(4), 682–691.

Rodriguez-Fornells, A., Krämer, U. M., Lorenzo-Seva, U., Festman, J., & Münte, T. F. (2011). Self-assessment of individual differences in language switching. *Frontiers in Psychology, 2*.

Rosselli, M., Ardila, A., Lalwani, L. N., & Vélez-Uribe, I. (2016). The effect of language proficiency on executive functions in balanced and unbalanced Spanish–English bilinguals. *Bilingualism: Language and Cognition, 19*(3), 489–503.

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.

Shedden, J. M., & Nordgaard, C. L. (2001). ERP time course of perceptual and post-perceptual mechanisms of spatial selection. *Cognitive Brain Research, 11*(1), 59–75.

Shi, B., & Shen, J. (2007). The relationships among family SES, intelligence, intrinsic motivation and creativity. *Psychological Development and Education, 23*, 30–34.

Struys, E., Woumans, E., Nour, S., Kepinska, O., & Van den Noort, M. (2018). A domain-general monitoring account of language switching in recognition tasks: Evidence for adaptive control. *Bilingualism: Language and Cognition,* 1–18.

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.

Verreyt, N., Woumans, E. V. Y., Vandelanotte, 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.

Wu, Y. J., & Thierry, G. (2013). Fast modulation of executive function by language context in bilinguals. *Journal of Neuroscience, 33*(33), 13533–13537.

Xie, Z., & Pisano, T. S. (2018). Second language (L2) proficiency, socioeconomic status (SES), and intelligence (IQ) are significant predictors of cognitive control differences among young adult unbalanced Chinese–English bilinguals. *Bilingualism: Language and Cognition,* 1–17.

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review, 111*(4), 931–959.