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Bidirectional Interaction between Language Control and Domain-general Executive Control in Unbalanced Chinese-English bilinguals*

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Recent research has shown that bilinguals outperform monolinguals on tasks requiring non-linguistic executive control skills, thereby generating an interest in the relationship between bilingual language processing and non-linguistic control abilities. Based on this, the present study further examined the bidirectional interaction between language control and non-linguistic control in unbalanced Chinese-English bilinguals. These bilinguals completed a Flanker task in three types of language control contexts (i.e., L1, L2, and Mixed language contexts) in the interleaved word-comprehension-to-Flanker sequence and performed a picture-word matching task in three types of non-linguistic executive control contexts (i.e., color, shape and color-shape mixed contexts) in the interleaved color-shape-switching-to-word-comprehension sequence. The results showed that the Flanker effect in mixed language context was smaller than in single (L1 and L2) context, suggesting language control leads to a better non-linguistic control ability. Additionally, the language switching cost was found smaller in the mixed task context (color/shape switching), indicating that non-linguistic control can enhance the language control ability. Therefore, we conclude that there is a bidirectional interaction between language control and non-linguistic control even in unbalanced bilinguals.

Keywords: bidirectional interaction, unbalanced bilingual, language control, executive control

Highlights:

- Language control had an effect on non-linguistic executive control.
- Non-linguistic executive had an effect on language control.
- The bidirectional interaction between language control and executive control

was found in unbalanced bilinguals.

Most people on earth can communicate in more than one language (Bialystok, 2017). Based on this linguistic phenomenon, a controversial claim is that language control involving reducing cross-linguistic interference and improving the selection of words from the target language is part of a more general executive control process (e.g., Calabria et al., 2015; Declerck et al., 2015; Jylkkä et al., 2018). Following this line, there is considerable debate about whether bilingualism confers non-linguistic benefits (e.g., Antoniou, 2019; Dick et al., 2019; Lehtonen et al., 2018; Paap, 2019).

Accumulating evidence showed that speaking a second language could lead to cognitive advantages by improving executive control in behavioral performance (e.g., Carlson & Meltzoff, 2008; Crivello et al., 2016; Hartanto & Yang, 2020; de Bruin et al., 2020). Some studies have also shown that there is an association between bilingual control and domain-general executive control, which is reflected in the correlation between the performance of two types of control tasks (e.g., Color/Shape switching task and Language switching task, Prior & Gollan, 2013; Voluntary language switching task and Intermixed mandatory/voluntary picture-naming task, Jevtović et al., 2020; Picture naming task and Visual perception classification task, Timmer et al., 2018). Additionally, neuroimaging research has found that domain-general executive control and language control shared neural circuits (e.g., De Baene et al., 2015; De Bruin et al., 2014). For example, it has been reported that a cortico-subcortical network involved in language control overlaps with the domain-general executive control network including the anterior cingulate cortex, inferior frontal cortex, basal ganglia, and parietal cortices (e.g., Abutalebi & Green, 2016; Baumgart & Billick, 2017; De Baene et al., 2015; Garbin et al., 2010; Weissberger et al., 2015). Beyond executive control, previous studies have also confirmed the positive effect of bilingualism on cognitive flexibility in a variety of tasks (Javan & Ghonsooly, 2018; Kharkhurin, 2017). Some of these studies have suggested that individuals with high bilingualism can choose correct responses by switching between tasks with a more efficient allocation of cognitive resources compared to individuals with low bilingualism (e.g., Luk et al., 2012; Hernández et al., 2013; De Baene et al., 2015).

However, there are other studies failing to replicate these results (Clare et al., 2016; Paap et al., 2014; Duñabeitia et al., 2014). For example, it was found that the behavioral performances in linguistic and non-linguistic switching tasks vary independently from each other, and so did linguistic and non-linguistic inhibition tasks (e.g., Declerck et al. 2019). Some previous studies examined whether bilingual language control was part of domain-general executive control by comparing between-language switching with color-shape non-linguistic switching and found that language control showed different patterns of switching costs and activated different areas of the brain (Calabria et al., 2012). Additionally, Nguyen and Astington (2013) failed to show that bilinguals outperformed monolinguals on executive function tasks. Thus, previous studies seemed to produce mixed results (e.g., Donnelly et al., 2019; Paap, 2019; van den Noort et al., 2019).

There are two potential explanations for these inconsistent observations. On the one hand, such findings may be confounded by differences in the tasks themselves as different tasks encompass different cognitive sub-processes that contribute to task performance. Wu et al. (2019) examined the reconstruction of the brain network for language and domain-general cognitive control and argued that bilinguals reconstructed their bilingual language control network from that of domain-general cognitive control. Similarly, Tran, Arredondo, and Yoshida (2019) claimed that the underlying mechanisms of language control were parts of a domain-general process and that the constant involvement of this process for language selection transfers to cognitive performance. Consistent with these perspectives, it was found that language-switching and task-switching share partially overlapping neurocognitive mechanisms (De Baene et al., 2015; Weissberger et al., 2012). Other studies comparing brain activity for the switching cost in the linguistic and non-linguistic domains for the same bilinguals reported not only some degree of overlapping activation but also a contribution of different regions (Branzi et al., 2016; Weissberger et al., 2015). Thus, language control and executive control would overlap partially but not completely. Following this line, whether the results show an overlap between language control and executive control or outperformance in bilinguals may depend on whether the tasks used to measure these two functions engage the overlapping function of language control and executive control or not.

On the other hand, low correlation values between linguistic and non-linguistic tasks do not necessarily mean that they involve different inhibitory abilities, but may reflect individual variations in other related factors. For example, it was found that the uncontrolled working memory span could lead to different performances of bilinguals and monolinguals (Antón et al., 2019). Thus, the relationship between domain-general inhibition and language control is far from clear. The previous findings support the hypothesis that language control implied by bilingualism interacts with the non-linguistic higher-order cognitive control. However, the current evidence is inadequate, for the reason that inconsistencies among these reported investigations. In order to reveal the nature of this interaction, an important research direction pertains to whether language control and non-linguistic executive control interact bidirectionally. It is also a critical issue to understand bilingualism advantage in general.

Prior research has shown that language control was required during bilingual speech production (e.g., Rodriguez-Fornells et al., 2005; de Bruin et al., 2014) and comprehension (e.g., Macizo et al., 2010; Durlik et al., 2016). The issue of whether language control and cognitive control share similar cognitive processes and neural mechanisms has been a popular topic in the study of language production (De Baene et al., 2015; Sikora et al.,2019; Jiao et al., 2020). However, few studies about this issue are reported in language comprehension. Additionally, in order to show a direct overlap between linguistic and cognitive control networks, a better control is to require the same participants to perform both linguistic and non-linguistic tasks. So far, only a few studies have used this direct comparison among the same participants (e.g., Coderre et al., 2016; De Baene et al., 2015), suggesting that highly similar brain circuits are involved in language control and domain-general cognitive control.

It is also important to note that the relative language proficiency is a critical factor affecting the neural response of the bilingual language control network. It is possible that the disparity in language proficiency may suggest a differential involvement of inhibitory control that is related to the degree of automatization of language switching. So far, most existing studies have been carried out on highly proficient bilinguals who acquired two alphabetic languages (e.g., Beatty-Martínez et al., 2019; Claussenius-Kalman et al., 2021; de Bruin et al., 2018; Declerck et al., 2019), For example, Struys et al. (2019) showed the performance of domain-general executive control was highly related to the language switch cost in a group of highly proficient Dutch-French bilinguals who performed the Simon task and a bilingual categorization task. However, few studies have focused on unbalanced bilinguals with low proficient L2. Moreover, as a non-alphabetic language, the language processing of Chinese is different from alphabetic languages (Chen et al., 2013). Thus, this cross-domain interaction should be reconsidered further in other types of bilinguals such as unbalanced Chinese-English bilinguals.

Taken together, the present study aims to address the bidirectional interactions between language control involved in comprehension task and non-linguistic executive control in unbalanced Chinese-English bilinguals. To investigate the causal effects of one upon the other, we adopted the cross-task-adaptation paradigm used in (Jiao et al., 2019), which utilizes a combination of a linguistic task (i.e., picture-word matching) and a non-linguistic paradigm (a Flanker task or a color-shape switching task), both of which are pseudo-randomly interleaved within the same experimental block. Specifically, to examine the effect of language control on non-linguistic executive control, we used a picture-word matching task to create three types of language control contexts (i.e., L1, L2, and L1-L2 mixed contexts) and then required the participants to complete the Flanker task in the interleaved word comprehension-to-Flanker sequence. To examine the effect of non-linguistic executive control on language control, we used a color-shape switching task to create three types of non-linguistic executive control contexts (i.e., color, shape, and color-shape mixed contexts), and then required the participants to complete the picture-word matching task in interleaved color-shape switching-to-word comprehension sequence. Thus, a picture-word matching task following a color-shape switching task was taken to measure the effect of executive control on language control, while a Flanker task following a picture-word matching task was taken to measure the effect of language control on executive control.

The Flanker task was usually used to measure domain-general inhibitory control, which included congruent and incongruent trials (Wu & Thierry, 2013). The response time in the incongruent trials is usually longer than in congruent trials and the difference is defined as the Flanker effect (an index of inhibitory control; e.g., Kang et al., 2020). We adapted a color-shape switching task to elicit participants' non-linguistic inhibitory control (Weissberger et al., 2015). During the switching trials, the participants were required to constantly monitor the task type in the current trial and inhibit the task type in the last trial. As a consequence, the inhibitory level is highly activated in color-shape switching context.

It was found that performance was improved more after practice on an easier compared to a more difficult version of a force tracking task (Onushko et al., 2014). Additionally, other studies showed that as the participants became more proficient at the task, they appeared to reduce the use of nonessential processes in the areas involved in higher level cognition (Schipul et al., 2012; Mehren et al., 2019). In this study, if the Flanker task was repeated in two sessions, participants would become more and more proficient at this task. Thus, the Flanker task would be more susceptible to the effect of repetition, with the extra practice providing a harmful effect on the involvement of executive control. For this reason, in this study, we use a color-shape switching task in the second session instead of the Flanker task.

There is evidence that unbalanced bilinguals have a larger switch cost for the dominant than for the non-dominant language (e.g., Schwieter & Sunderman, 2009) as their L1 proficiency is higher than the L2. Some investigators used this effect to indicate the higher effort required to release the increased inhibition in the dominant L1 as compared to L2 (Liu et al., 2016; Verhoef et al., 2009). Therefore, the language control of unbalanced bilinguals may vary across different contexts (i.e., L1 vs. L2 vs. L1-L2 mixed). According to previous studies (Jiao et al., 2020), we reasoned that if language control was linked to non-linguistic executive control (which comprised core subcomponents such as inhibitory control and cognitive flexibility), the Flanker effect would be smaller in the language mixed block that involved greater language control relative to the single language block (L1 and L2 blocks). By this logic, the linguistic switching cost as an index of language control would be smaller following switching trials in the color-shape switching task relative to those non-switching trials.

Method

Participants

Thirty-one unbalanced Chinese-English bilinguals (25 females, age: M = 21.24± 1.73 years, range: 18–27 years) participated in this study. All participants were right-handed with normal or corrected-to-normal vision. None of them had immigration or overseas education experience. They are Chinese native speakers (L1) and learned English as a second language (L2) at an average age of 9.1 years (SD = 2.4 years). They rated the proficiency in both Chinese and English in listening, speaking, reading, and writing on a 10–point scale, with higher scores indicating higher proficiency. The proficiency scores of Chinese and English were 9.4 ± 0.8 and 5.9 ± 1.8 in listening, 8.8 ± 1.3 and 5.1 ± 1.9 in speaking, 9.1 ± 1.1 and 6.7 ± 1.4 in reading, 8.4 ± 1.6 and 5.8 ± 1.8 in writing, respectively. The rating scores showed that their L1 proficiency level were significantly higher than that of L2 (listening: $t(32)$ =11.77, p < .001; speaking: $t(32)$ = 10.17, p < .001; reading: $t(32)$ = 9.44, p < .001;and writing: $t(32)$ =7.89, p < .001), indicating that they were late and unbalanced bilinguals.

They signed written informed consent and received payment for their participation. This study was approved by the Human Research Ethics Committee for Non-Clinical Faculties at the School of Psychology of South China Normal University.

Materials

Stimuli for the picture-word matching task

We selected 40 line drawings from Snodgrass and Vanderwart's (1980) normed picture set as stimuli for the picture-word matching task, which has been standardized for Mainland China participants (Shu et al. 1989) and widely used in picture-word matching task (e.g., Kazanas et al., 2020; Jiao et al. 2019; 2020). They were resized to

350–pixel height and 350–pixel width, each of which has a 2–to–3 character Chinese name and a 3–to–8–letter English equivalent (see supplementary A). Twenty new students who were from the same subject pool but did not contribute to the test data rated the familiarity of their Chinese and English names. There was no significant difference in the average familiarity (6.76 ± 0.30 vs. 6.76 ± 0.30: $t(39) = -0.20$, $p = 0.84$).

Stimuli for the Flanker task

Five arrows pointing to the left or right were used as stimuli in the Flanker task. A red or green circle and a red or green square were used as stimuli in the color-shape switching task.

Procedure

In the present experiment, all participants were presented with two different layouts of tasks, namely interleaved word-comprehension-to-Flanker sequence and interleaved color/shape-switching-to-word-comprehension sequence. The order of presentation was counterbalanced across participants. Participants were instructed about their task and familiarized with the picture stimuli prior to the experiment so that they could recognize the objects before the experiment began.

Procedure for interleaved word-comprehension-to-flanker sequence

The experimental procedure was similar to that of Jiao et al. (2020). All participants were presented with a linguistic task and a non-linguistic task. The linguistic task was a picture-word matching task, which was used to elicit different degrees of language control by creating three types of contexts, namely, single Chinese (L1; low language control), single English (L2; low language control), and mixed-language contexts (high language control). The non-linguistic task was a Flanker task, which included congruent and incongruent trials and was used to measure non-linguistic executive control.

To examine the effect of language contexts (language control) on non-linguistic control in unbalanced bilinguals, we interleaved the picture-word matching task with the Flanker task, resulting in a within-subjects design (see Figure 1A). The picture-word matching task was presented first. Its trial structure is as follows: After a 400 ms fixation, participants were presented with a national flag (a Chinese or American national flag) for 1000 ms, which indicated the response language for picture-word judgment with Chinese national flag for Chinese and American national flag for English. At the offset of the national flag, a picture and a Chinese or English word appeared onscreen. Participants were required to judge and orally report whether the picture matched the visual word (e.g., “apple” or “苹果”) as quickly and accurately as possible with yes or no. If participants did not respond, the picture and word would automatically disappear after 1,000 ms. In each single-language context, the language for oral report was the same as the target language, while in the mixed-language context, participants were required to orally report aloud in Chinese (L1) to avoid confounds associated with language production switching processes (Jiao et al., 2019).

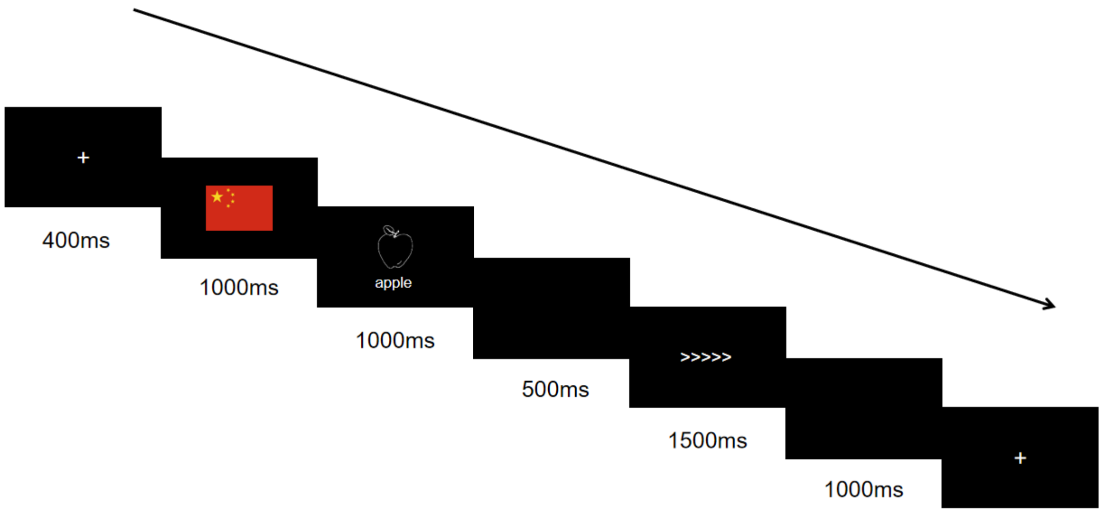
Then, the Flanker task came. Its trial structure is as follows: After a 500 ms blank, the target Flanker stimulus consisting of one of four 5-arrow arrays (> > > > >, > > < > >, < < < < <, or < < > < <) appeared onscreen. The middle arrow of the array was designated as the target to which the participants needed to respond, and the other letters were used as distractors. The participants were instructed to respond as quickly and accurately as possible to the pointing direction of the target arrow (< or >) by pressing the left or right button (i.e., “F” or “J” button on the keyboard) within 1500 ms. There was an inter-trial interval of 1,000 ms.

The present session comprised three separate blocks, namely single-L1, single-L2, and mixed-language contexts, with single-L1 and single-L2 blocks (their block order counterbalanced across participants) always appearing first. In each language context, there were 80 comprehension trials and 80 Flanker trials, which were pseudorandomly interleaved. Each picture in the visual picture-word matching task was presented twice in each block, and the proportion of trials was 50% matching and 50% mismatching. Before the experiment, participants practiced 20 trials to familiarize themselves with the experimental procedure.

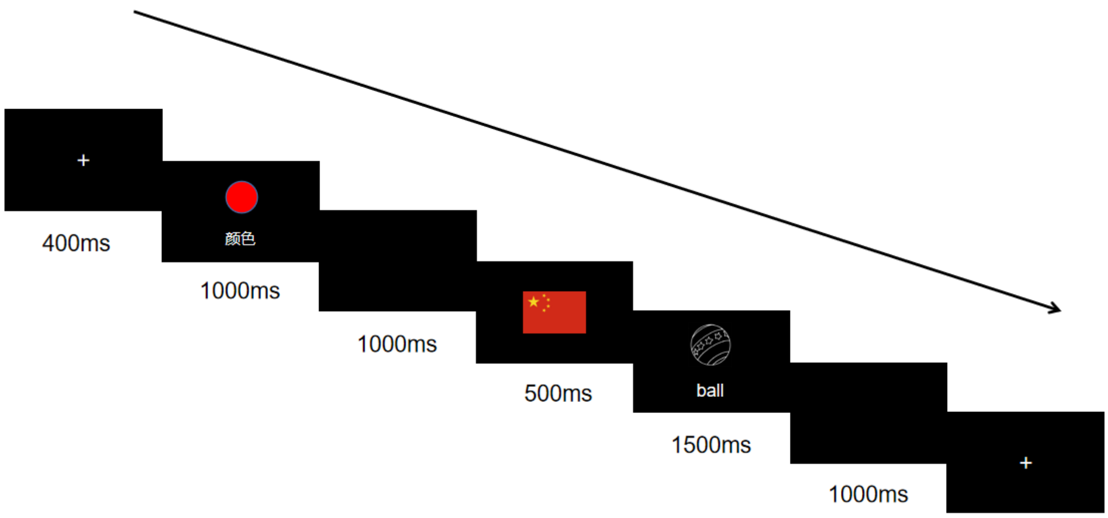
Figure 1

Trial protocols for interleaved word-comprehension-to-Flanker sequence (A) and interleaved color-shape switching-to-word comprehension sequence (B)

(A)



(B)



Procedure for interleaved color-shape-switching-to-word comprehension sequence

To examine the effect of non-linguistic executive control on language control in unbalanced bilinguals, we interleaved the color-shape switching task with a picture-word matching task (see Figure 1B). The color-shape switching task was used to elicit different degrees of non-linguistic control by creating three types of contexts, namely, single shape (low non-linguistic control), single color (L2; low language control), and color-shape mixed contexts (high non-linguistic control).

The color-shape switching task adapted from Prior and Gollan (2013) was presented first. Its trial structure is as follows: After a 400 ms fixation, participants were presented with a colored shape (i.e, red circle, red square, green circle, or red square) and were required to judge its color (red or green) or shape (square or circle) according to a task cue ("颜色" for color cue, and "形状" for shape cue) that appeared below. They were instructed to make responses as quickly and accurately as possible. The task cue and the stimulus remained onscreen until the participants made a response. If participants did not respond, they would automatically disappear after 1,000 ms.

Then, the picture-word matching task came. Its trial structure is identical to that in interleaved word-comprehension-to-Flanker sequence except that after a 1000 ms blank a national flag appeared for 500 ms onscreen. The present session comprised three separate blocks, namely single-color, single-shape, and color-shape mixed contexts, with single-color and single-shape blocks (their block order counterbalanced across participants) always appearing first. In each color-shape context, there were 80 color-shape trials and 80 picture-word matching trials, which were pseudorandomly interleaved. Voice-onset RTs were recorded with a microphone integrated with E-Prime. Response time was defined by the period between stimulus onset and the beginning of the audio signal corresponding to the participants' response. For each trial, the experimenter also collected response accuracy manually.

Results

Results of Flanker Task in the Interleaved Word Comprehension-to-flanker

Sequence

Overall, accuracy for the Flanker task was at the ceiling level (> 94%) and was not analyzed further. RTs less than 200 or greater than 1500 ms were excluded from analysis (1.4% of the data were omitted). In addition, RTs with wrong responses or exceeding ±3SD from the mean value of each condition were removed (3.6% of the observation). The reaction times and accuracy for the Flanker task are presented in Table 1.

Table 1

Mean RT (ms) and Accuracy (% and SE) of each condition for Flanker task

RT	Matching			Mismatching		
	Congruent	Incongruent	Flanker effect	Congruent	Incongruent	Flanker effect
Single language context	550 (11)	590 (13)	40 (7)	559 (12)	571 (13)	12 (6)
Mixed language context	527 (13)	541 (11)	14 (9)	540 (12)	543 (12)	3 (9)
Accuracy	Matching			Mismatching		
	Congruent	Incongruent		Congruent	Incongruent	
Single language context	96 (0.05)	94 (0.03)		98 (0.03)	96 (0.02)	
Mixed language context	95 (0.03)	97 (0.02)		96 (0.02)	97 (0.02)	

Data of Flanker effect calculated as incongruent response time (RT in ms) minus congruent RT were explored with a 2 (Language Context: Single language context vs. Mixed language context) × 2 (Matching Type: Matching vs. Mismatching) repeated measures ANOVA by participants with Language Context and Matching Type as within-subject factors.

There was a significant effect of Matching as shown by a smaller Flanker effect in mismatching condition (7 ms) compared with matching condition (27 ms; $F(1, 30) = 4.950$, $p = .034$, $\eta_P^2 = .142$). Importantly, the main effect of Language Context was reached significant ($F(1, 30) = 5.503$, $p = .026$, $\eta_P^2 = .155$). The Flanker effect in mixed language context (8 ms) was significantly smaller than Single context (26 ms). The interaction effect of Matching × Language Context was not significant (F (1, 30) =

1.904, p = .178, η_P^2 = .060). The results indicated that language control in mixed language context would facilitate conflict detection and conflict resolution in Flanker task, thereby resulting in an improvement in performance in incongruent trials of the Flanker task, namely conflict adaptation (a typical expression of cognitive control).

Results of picture-word matching task in the interleaved color/shape switching-to-word comprehension sequence

Overall, accuracy for picture-word matching task was at the ceiling level (> 95%) and was not analyzed further. RTs less than 200 or greater than 1200 ms were excluded from analysis (8.7% of the data were omitted). In addition, RTs with wrong responses or exceeding 3 SD from the mean value of each condition were removed (1% of the observation). The reaction times for the picture-word matching Task are presented in Table 2.

Table 2

Mean RT (ms) and Accuracy (% and SE) of each condition for picture-word matching task

RT	L1			L2		
	Non-switching	Switching	Switching cost	Non-switching	Switching	Switching cost
Single task context	849 (18)	877 (19)	28 (15)	882 (16)	927 (17)	45 (16)
Mixed task context	873 (19)	875 (19)	2 (10)	909 (16)	915 (22)	6 (12)
Accuracy	L1			L2		
	Non-switching	Switching		Non-switching	Switching	
Single task context	98 (0.02)	96 (0.03)		97 (0.03)	96 (0.03)	
Mixed task context	97 (0.03)	96(0.03)		95 (0.03)	95 (0.04)	

Data on switch cost (i.e., the RT differences between switch vs. non-switch conditions) were analyzed using two-way repeated measures ANOVA with context type (Single task context vs. Mixed task context) and language type (L1 vs. L2) as within-subject factors.

Results showed that there was a significant main effect of Context Type ($F(1, 30) = 5.417$, $p = .027$, $\eta_P^2 = .153$) with smaller switching cost in the mixed task context (4 ms) than in the single task context (36 ms). The main effect of Language Type was not significant ($F(1, 30) = .825$, $p = .371$ $\eta_P^2 = .027$). The interaction between Context Type and Language Type did not reach significance level ($F(1, 30) = .281$, $p = .600$, $\eta_P^2 = .009$). In order to better reveal the variation of switching cost, we further performed simple effect analyses. The switching cost was significantly smaller for the mixed task context (6 ms) than for the single task context (45 ms) in L2 condition ($F(1, 30) = 5.282$, $p = .029$, $\eta_P^2 = 0.150$), but there was no significance in L1 condition (2 ms vs. 28 ms; $F(1, 30) = 1.671$, $p = .206$, $\eta_P^2 = 0.053$).

Discussion

The present study investigated the bidirectional interaction between language control and domain-general executive control in unbalanced Chinese-English bilinguals by using a paradigm with executive control task interleaving with language comprehension task. The effect of language control on domain-general executive control was tested in the interleaved word comprehension-to-flanker sequence by using the Flanker effect, while the effect of domain-general executive control on language control was examined in the interleaved color-shape switching-to-word comprehension sequence by using language switching cost. The results showed that the Flanker effect in mixed language context was smaller than that in the single language context (i.e., L1 and L2), and the language switching cost was smaller in the mixed task context than that in the single task context. Thus, we report for the first time a bidirectional interaction between language control and domain-general executive control in unbalanced bilinguals.

Our findings complement those from previous studies reporting unidirectional effects between language control and domain-general executive control, that is, where language control affects domain-general executive control but domain-general executive control does not affect language control (e.g., Nichols et al., 2020; Prior &

Gollan, 2013). The interaction between them may be in accord with the general idea of a shared mechanism for language control and domain-general executive control (Declerck et al., 2019). However, this interaction may not indicate response-related processes between two tasks as they required different responses (orally reporting for language control task and pressing keys for executive control task), nor the effect of secondary cognitive processes, such as working memory span, which is involved in the current tasks but as the two tasks are solved sequentially there is no increment in working memory load from the preceding task.

Even in presence of a big difference in the result pattern (i.e., the main effect of language context was significant in Flanker task, while no significant difference of language type was found in picture-word matching task in the interleaved color/shape switching-to-word-comprehension sequence), both our tasks were successful in showing a bidirectional interaction between language control and domain-general executive control. Unlike previous studies using the comparison between bilinguals and monolinguals to address the relationship between language control and domain-general executive control (Costa et al., 2008; Chung-Fat-Yim et al., 2017; Bakker-Marshall et al., 2021), our study explored the interaction between the two by looking at the Flanker effect as well as at the language switching cost in the same bilingual. This was crucial to reveal that the interference of language control on executive control increased as the Flanker effect decreased in language mixed block as well as the interference of executive control on language control increased as switching cost decreased in task mixed block by reducing the effect of subjects trait at the subject level.

The current critical result was in line with the previous studies on language conflict: When dealing with conflict, mixed language context can enhance the bilingual's ability to suppress irrelevant information (e.g., Wu & Thierry, 2013; Liu et al., 2016; Kang et al., 2020). For example, Wu and Thierry (2013) argued that bilinguals' cognitive control was regulated by language context by showing better confliction resolution ability in mixed language context than in single language context. Jiao et al. (2020) also found that language context played an important role in the relationship between language control and executive control. According to the inhibition control model (Green, 1998), the inhibition on the non-target language involved cross-language suppression. In the mixed language context, participants need to switch between L1 and L2 frequently, resulting in persistent activation of both languages and robust interference suppression. Thus, task engagement and selective inhibition processes are involved in a mixed language context, but not in a single language context.

It was noteworthy that there was no interaction between the language context and the matching type in Flanker effect, which would mean the facilitating impact of language context only existed on interference inhibition, but not in reaction inhibition (Liu et al., 2016). As bilinguals need to constantly switch between two languages and avoid the interference of the non-target language. Such language switching training can facilitate domain-general executive control (Timmer et al., 2019), which explains why Flanker effect was smaller in the mixed language context than in the single language context. As for response inhibition, since the language use of bilinguals does not require them to inhibit habitual responses, their response inhibition ability was the same as that of monolinguals (Bialystok & Viswanathan, 2009; Fan et al., 2012).

Moreover, our results further support the adaptive control hypothesis which posits that the nature of the control mechanisms employed varies across different contexts (Green & Abutalebi, 2013; Green & Wei, 2014). Specifically, in order to adapt to more complicated language context, control processes and the higher demands on the executive control system would eventually improve executive function. As the non-target language is alternatively inhibited in a mixed-language block so that the target language could be processed appropriately, thus, the executive control remains active in the language mixed block. It explains the reason why language control affects the executive control function in the mixed-language context, but not in the single language context by demonstrating the changes in the performance of the nonverbal executive control in the current study. Our results support and extend previous studies by showing that there was a significant effect of language control on the domain-general executive control even in unbalanced bilinguals.

The language switching cost was considered as an index to measure language-specific control ability (e.g., Mishra & Singh, 2014; Declerck & Philipp, 2015).

Previous studies examined the effect of executive control on the bilingual language control function mainly by controlling participants' level of executive control. For example, it was found that people with a higher switching ability tend to have less language switching costs (e.g., Abutalebi & Green, 2008; Costa et al., 2006). Thus, in such between-subject design, the effect of executive control depends on the comparison between participants with high and low level of executive control. As we discussed previously, such key results on the overlap between executive control and bilingual language control would be potentially confounded by the effect of individual differences. Thus, the current study filled this gap in previous research by using a within-subject design.

This study showed the impact of executive control on language control by demonstrating the smaller language switching cost in the mixed task context than in the single task context. In the mixed task context, the non-target task in the current trial was suppressed and activated in the next trial, which cause strong interference to the task selection. Given that language switching and task switching depend on similar requirements (switching between mental sets), and that both are based on common processes of general switching skills, it is reasonable that task switching improves language-switching skills. During language comprehension, as new language information becomes available and is progressively decoded, it is passed up the hierarchy in a bottom-up fashion, which is different from the top-down fashion in language production (e.g., Cui et al., 2010; Qi et al., 2006). Thus, this study extends our knowledge of the mechanisms related to language comprehension and the role of executive control in this bottom-up fashion.

A few limitations of the current study should be highlighted. Firstly, compared to other relevant studies (e.g., around 6% in Costa et al. (2004)), this study had a higher attrition rate in the picture-word matching task (around 8%). The slightly higher attrition rate may be due to the inclusion of different types of participants. This study used unbalanced bilinguals, while Costa et al. (2004) used balanced bilinguals. Secondly, although our results showed a trend in the same direction and the simple effects were significant, we did not observe a significant interaction between Context

Type and Language Type. Thus, we suggest interpreting this result with caution. Thirdly, the exact nature of the mechanisms involved in the bidirectional interaction between language control and executive control remains unclear. Previous studies showed that executive control could consciously allocate the limited cognitive resources to a prioritized goal to meet the task demand (e.g., Qu et al., 2013). Additionally, the allocation of cognitive resources and the degree of executive control activation varied across different tasks. Given that the tasks used in the current study require a complex set of processes and that executive functions are related to various cognitive processes, this study is unable to reveal what specific mechanisms are likely to contribute to the effects of the interaction between language control and executive control. That is, we fail to provide evidence for the specific processing level at which language control and executive control are assumed to overlap. Future study could use individual tasks that enable the logical separation of different cognitive processes or EEG (Electroencephalogram) that could provide high temporal resolution information to reflect different cognitive processes.

Finally, in order to avoid the practice effect of the Flanker task, we used two different non-linguistic tasks in two sessions (i.e., the Flanker task and the color/shape switching task). However, it is possible that these two non-linguistic tasks do not share the same domain-general executive control. In order to better reveal the bidirectional interaction between language control and domain-general executive control, the Flanker task and its variation should be used in the two sessions (Flanker task would be better than color-switching task, as seen in our results). Future studies could develop a variation of the Flanker task that is similar to the Flanker task used in this study, but different enough to make sure participants do not improve their performance in the second set.

Conclusions

To summarize, our results are in accord with previous findings showing that language control and executive control interact in the human cognitive system. Moreover, we demonstrated for the first time in unbalanced bilinguals that the interaction between language control and executive control is bidirectional. This bidirectional interaction supports the idea that control in different specific domains is processed through a shared domain-general executive function mechanism.

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Dvosmerni uticaj između jezičke kontrole i opštih sposobnosti izvršnih funkcija kod nebalansiranih kinesko-engleskih dvojezičnih govornika

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Novija istraživanja su pokazala da su dvojezični govornici uspešniji od jednojezičnih u zadacima koji angažuju izvršne funkcije, te time stvorila interesovanje za povezanost dvojezične obrade jezika i nejezičke kognitive kontrole. U ovom istraživanju ispitan je dvosmerni uticaj između jezičke i nejezičke kontrole na uzorku nebalansiranih kinesko-engleskih dvojezičnih govornika. Ispitanicima je dat zadatak inhibicije konteksta (eng. flanker task) u tri tipa jezičke kontrole konteksta (tj. J1, J2 i mešoviti kontekst), u spojenoj sekvenci zadatak razumevanja reči – zadatak inhibicije konteksta. Dodatno, im je dat i zadatak uparivanja slika i reči u tri vrste nejezičke kontrole konteksta (tj. boja, oblik i mešoviti boja-oblik kontekst), u spojenoj sekvenci zadatak boje i oblika – zadatak razumevanje reči. Rezultati su pokazali da je efekat inhibicije konteksta (eng. flanker effect) manji u mešovitom nego jednojezičnom kontekstu (J1 i J2), ukazujući da jezička kontrola doprinosi boljoj sposobnosti nejezičke kontrole. Dodatno, nađeno je da je cena menjanja jezika manja u zadatku mešovitog konteksta (boja/oblik), ukazujući time da nejezička kontrola može da poveća sposobnost jezičke kontrole. Prema tome, zaključujemo da postoji dvosmerni uticaj između jezičke i nejezičke kontrole čak i kod nebalansiranih dvojezičnih govornika.

Ključne reči: dvosmerna interakcija, nebalansirani dvojezični govornici, jezička kontrola, izvršne funkcije

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