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The Role of Language Switching During Cross-Talk Between Bilingual Language Control and Domain-General Conflict Monitoring

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Abstract

The relationship between bilingual language control and executive control is debated. The present study investigated the effect of short-term language switching in a comprehension task on executive control performance in unbalanced bilinguals. Participants were required to perform a context task and an executive control task (i.e., flanker task) in sequence. A picture-word matching task created different language contexts in Experiment 1 (i.e., L1, L2, and dual-language contexts). By modifying the color-shape switching task, we created different contexts that do not involve language processing in Experiment 2 (i.e., color, shape, and dual context). Experiment 1 showed overall faster responses (in both congruent and incongruent trials) in the flanker task after a language switching context than after single (L1 or L2) contexts. This suggests that the language switching in a comprehension task affected general monitoring performance. By contrast, the nonlinguistic contexts in Experiment 2 did not affect flanker performance. This provides further evidence for the crucial role of language processing during switching to elicit short-term adaptions on domain-general conflict monitoring. Overall, our findings add to the previous studies by showing cross-talk between bilingual language control and domain-general conflict monitoring when language switching occurs in a comprehension task.

Keywords: Language switching; Language comprehension; Executive control; Monitoring

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1. Introduction

It is still an ongoing debate to what extent there is a relation between language control and executive control in bilinguals (for reviews, see Bialystok, 2017; Lehtonen et al., 2018; Wodniecka et al., 2020). It has been widely accepted that both languages are activated in parallel during bilingual language production (Jiao, Meng, Wang, Schwieter, & Liu, 2022; Kroll, Bobb, & Wodniecka, 2006; Kroll, Dussias, Bice, & Perrotti, 2015) and bilingual language comprehension (Marian & Spivey, 2003; Thierry & Wu, 2007). This suggests the engagement of control mechanisms during bilingual language processing. Regarding this cross-talk between bilingual experience and executive control, accumulating evidence revealed a facilitative effect of language switching on executive control based on language production processes (Jiao, Grundy, Liu, & Chen, 2020a; Timmer, Calabria, & Costa, 2019a), but the underlying mechanisms of language comprehension control affecting executive control remain unclear. Therefore, the present study manipulated short-term language and nonlinguistic switching contexts to investigate the origin of their impact on executive control performance.

1.1. Executive control: Conflict monitoring versus inhibition

Within domain-general cognitive tasks, executive control (also called executive function or cognitive control) refers to a collection of top-down control processes needed when automatic processes are insufficient to take action (Diamond, 2013; Miller & Cohen, 2001). Research on bilingualism and executive control has examined different executive control components, including *inhibition* and *monitoring* (Hilchey & Klein, 2011). Inhibition is the ability to control one's attention or suppress the presence of potent interference, whereas conflict monitoring is the ability to detect the presence of conflict or signal in the environment (Diamond, 2013; Hartanto & Yang, 2019). The flanker task is an ideal executive control task to measure both conflict monitoring and inhibition (Fan & Posner, 2004; Jiao et al., 2020a). In this task, participants indicate the direction of a central arrow (left or right) flanked by additional arrows pointing in the same (congruent) or the opposite direction (incongruent). When congruent and incongruent trials are intermixed, it is necessary to monitor the environment for potential changes in conflict-related demands (conflict monitoring) and when conflict is present, this can be resolved by employing inhibitory control (Timmer, Costa, & Wodniecka, 2021a; Timmer, Wodniecka, & Costa, 2021b).

The conflict monitoring and inhibition mechanisms are suggested to be related to language switching processes in bilinguals (Liu et al., 2019a; Liu et al., 2019b; Liu, Liang, Dunlap, Fan, & Chen, 2016; Timmer et al., 2019a). Language switching may seem easy, but given the parallel activation of two languages, bilinguals need to rely on mechanisms to monitor and resolve a conflict between competing representations (Kroll et al., 2015; Liu, Timmer, Jiao, & Wang, 2020). The classical language switching task consists of switch trials (i.e., trials whose target language is different from previous trials) and repeat trials (i.e., those whose target language is the same as the previous trial) (Liu et al., 2016). A switch cost, calculated by subtracting repeat trials from switch trials, is a quantitative index of local bilingual language control that occurs on a trial-by-trial basis. Moreover, some studies also investigate global language control (also called proactive control), comparing single language situations to repeat trials in mixed language situations (Timmer, Christoffels, & Costa, 2019b) indexing maintaining a goal while avoiding distraction (for reviews, see Bobb & Wodniecka, 2013; Wodniecka et al., 2020). Notably, some studies revealed that the control necessary to switch between languages was related to domain-general control abilities (Liu et al., 2016; Timmer et al., 2019a).

There are two lines of research in examining cross-talk between language control and executive control. One approach focuses on long-term bilingual experience in executive control by comparing different groups of individuals (Hartanto & Yang, 2016; Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016), which are commonly used to examine whether a bilingual advantage is seen after a long-term bilingual experience. Another, more recent approach pays attention to the short-term variation within one individual, which has been used to reveal the immediate effect of short-term language contexts on executive control (Jiao, Zhang, Plummer, Liu, & Chen, 2019, 2020a; Timmer et al., 2021a, 2021b; Wu & Thierry, 2013). Here, we followed this more recent approach and investigated the flexibility with which the cognitive system adapts to short-term changes in (language) contexts.

1.2. Effects of language switching in a production task on executive control

A prominent bilingual language control model is the Inhibitory Control (IC) model (Green, 1998), focusing on language control in production tasks. The core point of the IC model is that during language production, bilinguals could switch away from a language by exerting inhibition and switch to a particular language by releasing inhibition (Jiao et al., 2022; Liu et al., 2016; Liu, Zhang, Blanco-Elorrieta, He, & Chen, 2020). Taking the picture naming task as an example, the picture presented on the screen (i.e., an object) can elicit two candidates (i.e., L1 and L2 words, respectively). When encountering such conflict, bilinguals have to inhibit one of the candidates to produce accurate words.

Expanding to the domain-general executive control domain, accumulating evidence suggests that language switching in a production task affects domain-general control performance (Hilchey & Klein, 2011; Liu et al., 2016, 2019b; Timmer et al., 2019a; Zhang, Kang, Wu, Ma, & Guo, 2015). Studies with enough language switching training in a production task improved different facets of domain-general cognitive control: either local task-switching ability as indexed by reduced task-switch costs (e.g., Timmer et al., 2019a) or global control, as was reflected in reduced task-mixing costs (e.g., Liu et al., 2019b; Zhang et al., 2015). The discrepancy in the type of control mechanisms affected could be the use of different experimental tasks and group comparisons. Different tasks (e.g., task-switching, AX-CPT, and faces task) employ cognitive control measures to a different extent. Crucially, all these studies employed one group with language switching training in a production task and impacted domain-general cognitive control (for a review, see Wodniecka et al., 2020). Moreover, the difference between the type of training each group receives also impacts the control mechanisms that were affected. The present study manipulates (short-term) language contexts and investigates whether inhibition or conflict monitoring is enhanced in bilingual auditory language comprehension.

1.3. Effects of language switching in a comprehension task on executive control

Language switching in production and comprehension tasks relies on control mechanisms to a different extent (Blanco-Elorrieta & Pylkkänen, 2016). Unlike the inhibition mechanism needed during production, bilinguals may depend to a greater extent on monitoring when comprehending words of two languages within a conversation (Blanco-Elorrieta & Pylkkänen, 2016; Struys, Woumans, Nour, Kepinska, & Van den Noort, 2019). During language comprehension, each word is presented in one language (i.e., L1 or L2), while during language production (naming pictures), there are two languages to choose from. Hence, monitoring mechanisms may be more critical during bilingual language comprehension than inhibitory processes (Jiao et al., 2019; Jiao, Liu, de Bruin, & Chen, 2020b; Struys et al., 2019).

The effect of bilingual language comprehension on executive control has been investigated by comparing the immediate performance on a flanker task during (short-term) single- versus mixed-language contexts (Jiao et al., 2019, 2020b; Timmer et al., 2021a, 2021b; Wu & Thierry, 2013). For example, Jiao et al. (2019) used a picture-word matching task to create (short-term) single- and mixed-language contexts and used the flanker task to measure executive control performance. In a cross-task-adaptation paradigm, the language comprehension trial was interleaved with flanker trials to investigate whether the short-term changes in a language comprehension context influenced subsequent flanker trials. The results showed overall faster responses in the flanker task (i.e., across congruent and incongruent trials) in mixed-language context than in single-language context (Jiao et al., 2019), suggesting that the short-term language context in a comprehension task facilitated conflict monitoring. Electrophysiological (EEG) studies provided additional evidence for enhanced conflict monitoring by revealing overall increased efficiency on both trial types for the N2 and P3 components in a mixed-language context compared to a single-language context. Thus, both behavioral and EEG data suggest that performing the flanker task in a mixed-language context relies on early conflict monitoring processes (Jiao et al., 2020b; Timmer et al., 2021a, 2021b).

In contrast, the seminal study by Wu and Thierry (2013) found enhanced inhibition (i.e., smaller flanker effect) instead of enhanced conflict monitoring (i.e., overall faster response times [RTs]) after short-term language context manipulations. The difference between the above two studies is that Jiao et al. (2019) used an overt language comprehension task to increase comprehension demand, while Wu and Thierry (2013) presented the words of two languages with no specific requirement. Recently, sentences with and without code switches also enhanced inhibition (Adler, Valdés Kroff, & Novick, 2020). The reason for the seemingly inconsistent results between Jiao et al. (2019) and Wu and Thierry (2013) could be that the origin of the enhancement is at an earlier point (alertness/conflict monitoring) than assumed before (inhibition) (Timmer et al., 2021a, 2021b). Timmer and colleagues show that language switches have an alerting effect (N1 component) similar to arbitrary cues. The alert state enhances the processing of upcoming information (e.g., flanker) but paradoxically increases the flanker effect, as suggested by greater enhancement for congruent than incongruent trials (Timmer et al., 2021a, 2021b). In line with this, recent models on the cross-talk between bilingualism and executive control suggest that conflict resolution operates through earlier attentional mechanisms (i.e., alertness and attention) (Dong & Li, 2020).

Although the cross-task-adaptation paradigm has been widely used, there is one limitation of this paradigm. In the dual-language context (i.e., mixed-language context), the language switching process (i.e., between L1 and L2) is always accompanied by the task switching process. Therefore, additional switching between language processing trials and nonlinguistic task trials (e.g., flanker trials) occurs. This additional switching procedure might impact an individual's performance on top of language switching itself. In addition, the interleaved language processing trials and flanker trials make it difficult to measure behavioral performance in context tasks (i.e., language processing) in a cross-task-adaptation paradigm (Jiao et al., 2019). The present study tried to overcome this limitation by using a blocked paradigm in which the two tasks are performed in separate blocks allowing for performance measurement in the context task without trial-to-trial changes between language-processing and flanker tasks (Jiao et al., 2019).

1.4. The present study

By manipulating short-term changes in language contexts, the present study explored if and how language switching in a comprehension task affects executive control performance. This question was explored through two types of short-term switching contexts: the language switching context with language comprehension in Experiment 1 and the *modified* color-shape switching context in Experiment 2. There is no need for language processing in the latter context, while it does require visual switching.

In line with previous studies, Experiment 1 consisted of three short-term language contexts (i.e., single-L1, single-L2, and dual-language contexts) by manipulating the languages in a picture-word matching task. Executive control performance (i.e., conflict monitoring and inhibition) was measured in the flanker task. However, unlike previous studies (Jiao et al., 2020b; Timmer et al., 2021a, 2021b; Wu & Thierry, 2013), the present study used a blocked paradigm. This paradigm presents the three language contexts (picture-word matching task) as separate blocks before the flanker task instead of interleaving the context with the flanker trials. Based on previous studies using an interleaved paradigm with language comprehension (Jiao et al., 2019, 2020b; Timmer et al., 2021a, 2021b), we predict that conflict monitoring will be enhanced during the dual-language context compared to the single-language context. Overall, shorter response latencies in dual-language contexts would reflect enhanced conflict monitoring for congruent and incongruent trials. This is also in line with the adaptive changes in language control processes (Adaptive Control hypothesis, Green & Abutalebi, 2013). Furthermore, we do not predict enhanced inhibition (i.e., flanker effect indexed by a smaller difference between incongruent and congruent trials) in a dual-language context as compared to a single-language context.

In Experiment 2, we tested whether these short-term adaptations were due to general switching or language processing. This was achieved by replacing the word stimuli of the context task in Experiment 1 with colored shapes, removing language processing from Experiment 2. As in Experiment 1, the context task included two single- and one dual-context and an executive control task in sequence using a blocked paradigm. In the context task, participants switched between decisions on colors (i.e., red or blue) and shapes (i.e., triangle or quadrangle) in a *modified* switching task. Critically, this task differed from the classical color-shape switching task as our target stimuli were univalent instead of bivalent. In the classical color-shape switching task, a target picture simultaneously contains color information and shape information (e.g., a red square). This means that one picture stimulus elicits two possible responses (e.g., red or square), similar to language production processes in bilinguals. However, since bilinguals' word comprehension processes only correspond to one language (L1 or L2), we presented only the color or shape dimension for nonlinguistic stimuli. Therefore, each stimulus in the color-shape switching task only elicited one response. Furthermore, the executive control (i.e., flanker) task was the same as in Experiment 1.

In sum, the present study concentrates on the origin of cross-talk between language switching during comprehension and executive control by manipulating different short-term contexts and examining their effects on the flanker task. Experiment 1 tests whether switching between languages enhances monitoring during domain-general processing as found in previous studies using an interleaving paradigm (Jiao et al., 2019, 2020b; Timmer et al., 2021a, 2021b). Then, Experiment 2 investigates whether the underlying mechanism is simply switching between categories or requires deeper linguistic processing. If language processing is not crucial for cross-talk, color-shape switching will also modulate flanker performance. If language processing plays a critical role, no adaptations are expected due to color-shape switching.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-nine students from Beijing Normal University participated in the study for monetary compensation. All participants were Chinese (L1)–English (L2) bilinguals who provided written informed consent. They were right-handed bilinguals with normal or corrected-to-normal vision. Ethical approval was obtained from the Committee of Protection of Subjects at Beijing Normal University. Data from one participant were excluded due to low accuracy (<70%). The final sample consisted of 28 participants (20 females), aged 18–28 years old ($M = 19.93$, $SD = 2.60$). All participants were born in China and had no migration experience or overseas education. They were exposed to L1 (Chinese) from birth and learned L2 (English) at a mean age of 7.4 ($SD = 2.3$) years in a classroom setting. Hence, participants have a homogeneous cultural- and language-learning background. In addition, all participants often switch between two languages in the school environment, especially when taking the College English course. Language proficiency was measured by Oxford Placement Test (OPT) and a self-rating questionnaire.

The OPT mainly assesses an individual's reading comprehension ability. The OPT consists of a cloze test (i.e., reading a text and supplying the missing word that has been removed from the text) and 25 multiple-choice questions. As an objective indicator of L2 proficiency, the higher the score is, the higher the English proficiency of the participant (Liu et al., 2016).

Table 1
Means and SDs of AoA and language proficiency in four language skills

	Experiment 1		Experiment 2		Independent-sample *t* test	
	L1	L2	L1	L2	L1	L2
AoA	—	7.4 (2.3)	—	8.3 (2.6)	—	–1.27
OPT	—	40 (5.2)	—	39 (4.0)	—	0.63
Listening	5.6 (0.7)	3.8 (1.1)	5.6 (0.6)	3.3 (1.3)	0.33	1.37
Speaking	5.1 (0.9)	3.5 (1.0)	5.2 (0.6)	3.2 (1.0)	–0.85	0.85
Reading	4.8 (0.8)	2.9 (1.1)	5.0 (0.9)	3.1 (1.5)	–0.96	–0.61
Writing	4.6 (0.9)	3.6 (1.3)	4.7 (0.9)	3.0 (1.4)	–0.48	1.49

Abbreviations: AoA, the age of L2 acquisition; independent-sample *t* test, the *t* values for the comparison of participants' language background between Experiment 1 and 2; OPT, the score of the Oxford Placement Test.

The maximum score of OPT is 50. Participants in both experiments had an average score of approximately 40 (Table 1). This score suggests that participants have a good level of English and have no difficulty completing our experiment. Moreover, a subjective indicator of language proficiency was obtained from a self-rating questionnaire consisting of listening, speaking, reading, and writing skills for L1 and L2 language proficiency (Liu, Wang, Timmer, & Jiao, 2022). Language proficiency was rated on a 6-point scale, in which 1 suggested "very nonproficient," and 6 suggested "very proficient." Paired-samples *t*-tests showed a significant difference between proficiency scores for L1 and L2 in all the four skills, listening: $t(27) = 7.08$, $p < .001$; speaking: $t(27) = 5.77$, $p < .001$; reading: $t(27) = 11.59$, $p < .001$; and writing: $t(27) = 3.71$, $p < .001$. In sum, participants were unbalanced bilinguals, with the native language being dominant and a good level of English (Table 1).

2.1.2. *Design and procedure*

Experiment 1 consisted of three blocks (i.e., L1-flanker, L2-flanker, and dual-flanker). The order of these blocks was counterbalanced across participants with a short break between blocks. As shown in Fig. 1, each block started with an auditory picture-word matching task, used to create language contexts, followed by the flanker task (Jiao et al., 2019). Each trial consisted of a picture presented in the center of the computer screen, accompanied by a word that was played simultaneously through headphones. Participants had to judge whether the picture matched the word that they heard. The picture remained on the screen until the participant responded or for a maximum duration of 1500 ms, followed by a blank inter-trial-interval of 1000 ms. Participants were asked to press the "T" button for matching trials and the "B" button for mismatching trials. The response keys were counterbalanced across participants. RTs were measured from picture/word onset.

Each language comprehension task consisted of 60 trials. In half of the trials, the picture and auditory word presented together matched, and in the other half, they mismatched. Only Chinese or English words were presented in the single L1/L2 contexts, while in the dual-language context, both Chinese and English words (equal number of language trials within each block) were presented. In the dual-language context, half of the trials were switch trials

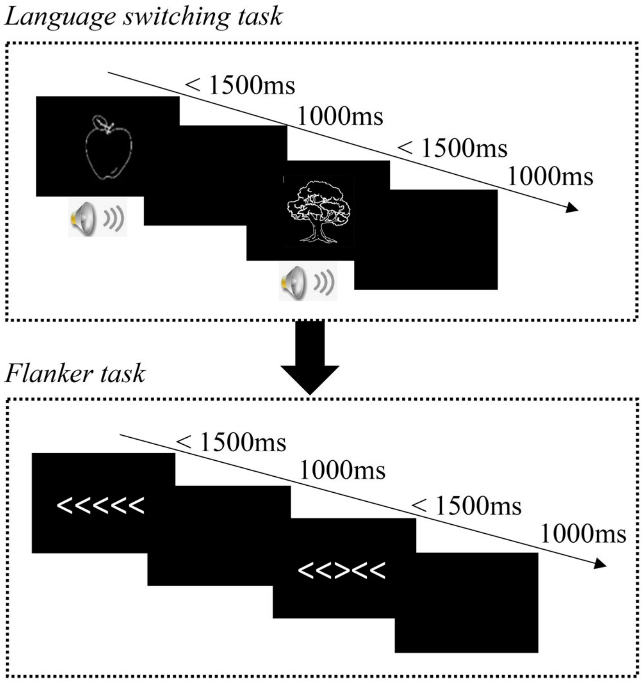

Fig. 1. Experimental procedure in Experiment 1.

(i.e., switching from another language to the target language) and the other half were repeat trials (i.e., repeating the same language in two subsequent trials).

The picture stimuli consisted of 60 black-and-white line drawings, which were selected from Snodgrass and Vanderwart's (1980) photo gallery and were standardized by Zhang and Yang (2003). Most of the Chinese words for picture stimuli were two-character words, and the English equivalents ranged between 3 and 8 letters ($M = 4.5$, $SD = 1.3$) (see Appendix A). Based on the standardized dataset for Chinese–English bilinguals (Zhang & Yang, 2003), the image-word agreement of picture items was 3.61 ($SD = 0.45$) on a 5-point scale (i.e., 1 = low agreement and 5 = high agreement); the visual complexity of picture items was 2.33 ($SD = 0.73$) on a 5-point scale (i.e., 1 = very simple and 5 = very complex). To control for the familiarity of picture names (i.e., Chinese and English words), we tested the familiarity of the picture names on a 7-point scale with a different group of 25 students who had similar L2 proficiency to the participants in the present study. Higher scores indicated a higher level of familiarity. Results showed that the familiarity of Chinese words ($M = 6.55$, $SD = 0.29$) was similar to the English words ($M = 6.57$, $SD = 0.24$), $t = -0.57$, $p = .57$. The auditory material for each picture was recorded in a soundproof room by a female speaker who is a proficient Chinese–English bilingual. Before the experimental task, participants were familiarized with the pictures and their corresponding names in L1 and L2. Participants saw each picture twice during the familiarization phase: once with the Chinese names and once with the English names presented over headphones. Given the dominant language of participants being

Chinese, the language of instruction for the familiarization phase and practice phase was Chinese. However, the instructional language matched the language context during the language contexts (e.g., Chinese instruction for the Chinese context or instruction in two languages for the dual-language context).

In the executive control task that followed each language context, participants performed the flanker task (Eriksen & Eriksen, 1974). Participants had to indicate whether a central target arrow pointed to the left or right. For congruent trials, the four flanking arrows pointed in the same direction as the central arrow (i.e., < < < < < or > > > > >). For incongruent trials, the flanking arrows pointed in the opposite direction of the central arrow (i.e., < < > < < or > > < > >). Participants were required to respond as quickly as possible to the direction of the central arrow by pressing the left or right button (i.e., "F" or "J") on the keyboard. The flankers were presented in the center of the screen and remained until a response was given or 1500 ms had passed. Each trial was separated by a blank screen for 1000 ms. There were 60 flanker trials (30 congruent trials and 30 incongruent trials) after each language context.

2.1.3. Data analysis

The data were analyzed with linear mixed-effects models in R computing environment (lme4 package; Bates, Mächler, Bolker, & Walker, 2015). For the RT analysis, trials with incorrect responses or RTs beyond a mean of ± 3 SDs per condition were excluded (Jiao, Liu, Schwieter, & Chen, 2021). Hence, 5.34% of the data in the picture-word matching task and 4.46% in the flanker task were excluded.

In the picture-word matching task, the fixed effect was Context. In the flanker task, the fixed effects included Context, Congruency, and their interaction. We used the sum coding scheme for the two-level variable Congruency (congruent = –0.5, incongruent = 0.5) and the Helmert coding scheme for the three-level variable Context. Specifically, the first contrast for Context variable compared single-language context (i.e., the average of L1 and L2 contexts) to dual-language context (L1 = –1/3, L2 = –1/3, and dual = 2/3). The second contrast compared the two single-language contexts to each other (L1 = –0.5, L2 = 0.5, and dual = 0). Mixing costs were calculated by subtracting the single trials in L1/L2 context from the repeat trials in the dual-language context. Considering the unequal number of trials between repeat and single trials, only even trials from the single language context were entered into the analysis for mixing costs (Jiao et al., 2019).

Subjects and items were included as random effects in the models for context tasks, while only subjects were included as random effects for flanker tasks. We started with a full model for each analysis, including all fixed effects, random intercepts, and random slopes for all predictors (Barr, Levy, Scheepers, & Tily, 2013). Then, if models failed to converge, we followed a backward-fitting procedure to identify a model that would converge. Using likelihood-ratio tests, we assessed the contribution of each random slope to each model and reported the best-fitting model justified by the data. Absolute t values greater than 2 indicate significance at the $\alpha = 0.05$ level (Baayen, 2008).

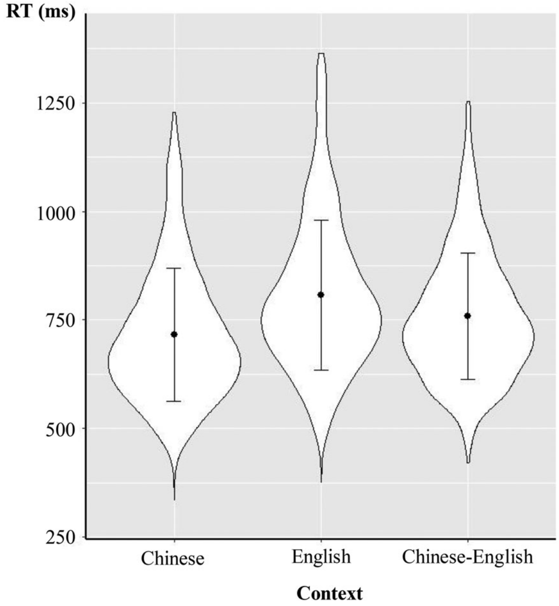

Fig. 2. Violin plots showing the RTs of the picture-word matching task for each language context. The violin plot outline shows the density of data points for different RTs. The black dot represents the mean value, while the thin vertical black line represents the standard deviation.

Table 2
Fixed effects structure for the mixed-effects model of RTs in picture-word matching task

Fixed effects	Estimate	SE	*t*
(Intercept)	765.02	13.77	55.61***
Context (single vs. dual)	5.32	9.66	0.55
Context (L1 vs. L2)	62.57	20.69	3.02**

***$p < .001$.
**$p < .01$.

2.2. Results

2.2.1. Picture-word matching task

Fig. 2 depicts the RTs for picture-word matching task in L1, L2, and dual-language contexts. The model for picture-word matching task included Context as a fixed effect, with the by-subject random slope for Context and the by-item random intercept. Table 2 summarizes the fixed effects structure for the mixed-effects model. There was a significant effect of Context between the L1 and L2 contexts, with faster responses in the L1 context ($M = 716$ ms) than in the L2 context ($M = 807$ ms), $t = 3.02$, $p = .005$, $d = 0.33$. Despite no significant difference between single-language and dual-language contexts ($t = 0.55$, $p = .59$, $d = 0.03$), the RT in the dual-language context ($M = 758$ ms) lied in between the two single-language

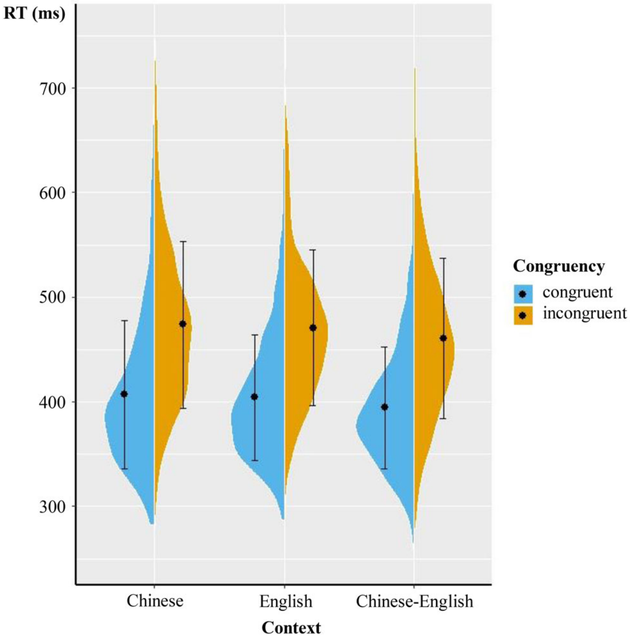

Fig. 3. Split violin plots showing the RTs of the flanker task (Experiment 1) for each language context for each trial type (congruent and incongruent trials). The black dot represents the mean value, while the thin vertical black line represents the standard deviation.

contexts, with slower response than in the L1 context ($t = –2.98$, $p = .005$, $d = 0.20$) and slightly faster responses than in the L2 context ($t = 1.65$, $p = .11$, $d = 0.14$).

Moreover, there was no switch cost in the dual-language context, with similar RTs for switch trials ($M = 750$ ms, $SD = 77$) and repeat trials ($M = 757$ ms, $SD = 76$), $t = 1.60$, $p = .12$, $d = 0.09$. The mixing cost was observed in both the L1 (single trials: $M = 727$ ms, $SD = 81$; $t = –2.42$, $p = .02$, $d = 0.38$) and L2 (single trials: $M = 802$ ms, $SD = 103$; $t = 2.87$, $p = .008$, $d = –0.49$).

2.2.2. *Flanker task*

Because accuracy was quite high overall (> 95%), only RTs in the flanker task were analyzed. Regarding the model for RTs in the flanker task, fixed effects included Context, Congruency, and their interaction with the by-subject random slopes for Context and Congruency. Fig. 3 depicts the RTs for the flanker task in L1, L2, and dual-language contexts. Table 3 summarizes the fixed effects structure for the mixed-effects model in the flanker task. First, across three contexts, there were faster responses for congruent trials ($M = 402$ ms) than for incongruent trials ($M = 468$ ms), $t = 22.18$, $p < .001$, $d = 0.84$. Second, across congruent and incongruent flanker trials, the RTs in the dual-language context ($M = 427$ ms) were significantly shorter than in the single-language contexts ($t = –4.27$, $p < .001$, $d = –0.15$). Further analysis using dual-language context as the baseline showed that the RTs in the dual-language

Table 3
Fixed effects structure for the mixed-effects model of RTs in the flanker task of Experiment 1

Fixed effects	Estimate	SE	*t*
(Intercept)	435.36	6.74	64.59***
Context (single vs. dual)	–11.55	2.70	–4.27***
Context (L1 vs. L2)	–2.76	6.48	–0.43
Congruency (congruent vs. incongruent)	65.77	2.97	22.18***
Congruency × Context (single vs. dual)	–0.18	3.64	–0.049
Congruency × Context (L1 vs. L2)	1.90	4.20	0.45

***$p < .001$.

context were shorter than in both the L1 ($M = 439$ ms, $t = 3.09$, $p = .004$, $d = 0.17$) and L2 contexts ($M = 437$ ms, $t = 2.39$, $p = .02$, $d = 0.13$). There was no significant difference between the two single-language contexts.

2.3. Discussion

In sum, the results of Experiment 1 revealed that short-term language switching in a comprehension task exerted an immediate effect on conflict monitoring, as reflected by faster RTs on the flanker task in the dual-language context compared to single-language contexts. In the dual-language context, participants need to switch back and forth between two languages. Hence, they continuously monitor possible language changes to adjust the relative activation levels of their two languages when required (Wodniecka et al., 2020).

Our findings are supported by previous studies in the literature. For example, a reverse Stroop effect revealed that color-matching (i.e., visual information) affected word-matching (i.e., verbal information) processing (Durgin, 2000). However, changing the ink color of words in a monolingual context did not change EEG activation during the Attentional Network Test (i.e., an extension of the flanker task). In contrast, bilingual language context did modulate EEG activation (i.e., the P3 component) (Timmer et al., 2021a). Thus, it is not clear whether the effect of language switching on conflict monitoring comes from language information processing or just from general switching. To identify the underlying mechanism of domain-general monitoring modulations, Experiment 2 used the same paradigm as Experiment 1, but without language processing during the short-term Context part.

3. Experiment 2

3.1. Method

3.1.1. Participants

Thirty unbalanced Chinese (L1)–English (L2) bilinguals participated in the study for monetary compensation. All participants were recruited from Beijing Normal University and provided written informed consent. They were right-handed bilinguals with normal or corrected-to-normal vision. Data from one participant were excluded due to his/her accuracy being

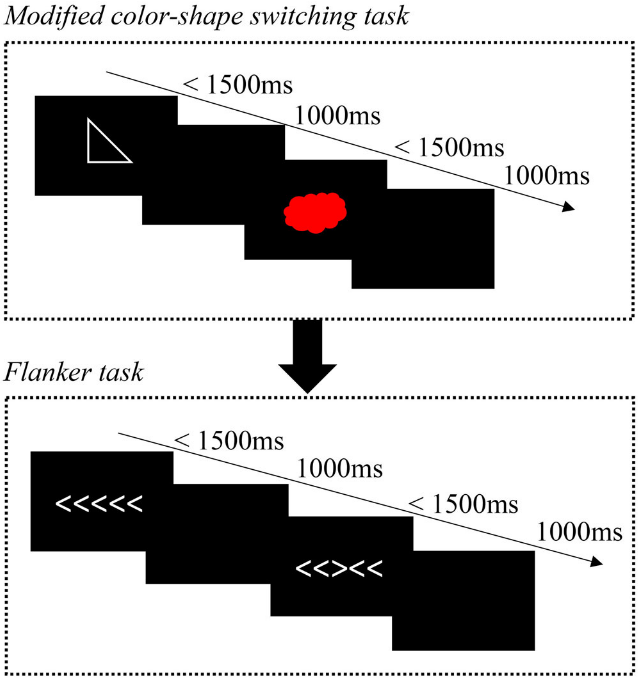

Fig. 4. Experimental procedure in Experiment 2.

below 70% in the context task. The final sample consisted of 29 participants (17 females), aged 19–26 years old (*M* = 22.6, *SD* = 1.9). None of the participants have any migration background. As in Experiment 1, participants were asked to assess their L1 and L2 language proficiency with the OPT and a self-rating questionnaire. The average proficiencies for L1 and L2 are presented in Table 1. Paired-samples *t*-tests showed significant differences between proficiency scores of L1 and L2 in all four skills (listening: $t(28) = 10.67, p < .001$; speaking: $t(28) = 11.18, p < .001$; reading: $t(28) = 8.67, p < .001$; and writing: $t(28) = 8.48$, $p < .001$). In addition, there were no significant differences in language background measures between the participants in Experiment 1 and Experiment 2 (Table 1).

3.1.2. Design and procedure

The design and procedure were the same as in Experiment 1. The only change is in the context task: a *modified* color-shape switching task requiring color/shape information processing, without the need for language processing (Fig. 4). The present task differed from typical color-shape task switching in that each target stimulus is univalent with only one dimension (i.e., color or shape) instead of bivalent with two dimensions. Therefore, in the present modified task, the dimension on which the decision is to be made is not ambiguous, but instead, the target stimulus indicates the dimension (i.e., color or shape) to respond to.

Just like in Experiment 1, two single-contexts and one dual-context were created. In the single-contexts, only one of the dimensions was present. Specifically, in the shape context, triangles or quadrangles were presented in the center of the computer screen. All shapes were presented as a white outline without colors. In the color context, red or blue color patches were presented without a geometric shape. In dual-context, both stimuli types from the single contexts were intermixed randomly. Notably, all stimuli are univalent, consisting of only one dimension to respond to. In the color condition, participants were asked to press the "T" button for red trials and the "B" button for blue trials. In the shape condition, participants were asked to press the "T" button for triangle trials and "B" button for quadrangle trials. The response keys were counterbalanced across participants. Given the diversity of word stimuli in Experiment 1, we created variation in the nonlinguistic stimuli by manipulating the transparency of the colored stimuli and rotating the direction for the shaped stimuli to maximally parallel to the contextual task in Experiment 1.

As in Experiment 1, three blocks (i.e., color-flanker, shape-flanker, and dual-flanker) were presented with short breaks in between, and the blocks were counterbalanced across participants. During the preceding color-shape switching task, each stimulus remained on the screen until either the participant responded or for a maximum duration of 1500 ms, followed by a blank buffer of 1000 ms. There were 60 trials in the modified color-shape switching task in each block. Immediately following the modified color-shape switching task, participants performed the flanker task to measure executive control performance.

3.1.3. Data analysis

As in Experiment 1, all data of Experiment 2 were analyzed with linear mixed-effects models in the R computing environment (lme4 package; Bates et al., 2015). For the RT analysis, trials with incorrect responses and RTs with an SD of 3 or larger per condition were excluded. This resulted in 4.14% of the modified color-shape switching task trials and 3.60% of the trials in the flanker task being excluded. As in Experiment 1, the fixed effect was Context in the modified color-shape switching task. Moreover, we also calculated the switch and mixing costs in the modified color-shape switching task. In the flanker task, the fixed effects included both Context, Congruency, and their interactions with the same contrasts included as in Experiment 1. The procedures of model selection were also in line with Experiment 1.

3.2. Results

3.2.1. Modified color-shape switching task

Fig. 5 depicts the RTs in the modified color-shape switching task separated for the three contexts. The model for RT of modified color-shape switching task included Context as a fixed effect, with the by-subject random slopes for Context and the by-item random slope for Context. Table 4 summarizes the fixed effects structure for the mixed-effects model in the modified color-shape switching task. There was a significant difference between single-contexts and dual-context, with slower responses in dual-context ($M = 539$ ms) than in single-contexts ($M = 430$ ms; $t = 12.08$, $p < .001$, $d = 0.88$). Further analysis with dual-context as the baseline showed the RTs in dual-context were longer than both the single color-context ($M = 425$ ms, $t = 10.60$, $p < .001$, $d = 0.82$) and the single shape-context ($M = 436$ ms, t

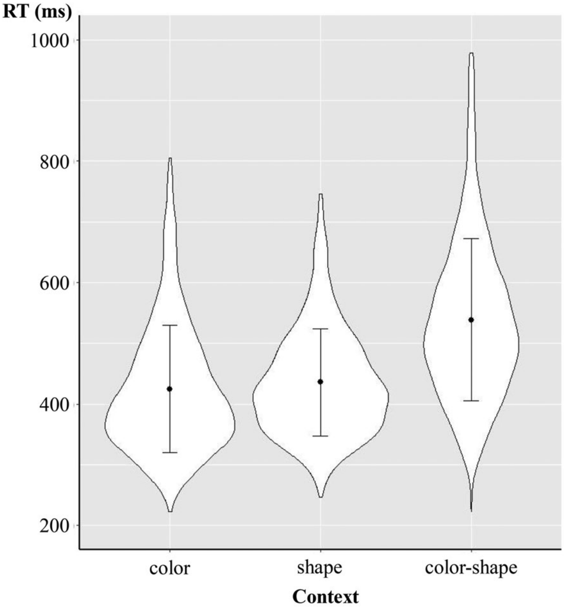

Fig. 5. Violin plots showing the RTs of the modified color-shape switching task for each context. The violin plot outline shows the density of data points for different RTs. The black dot represents the mean value, while the thin vertical black line represents the standard deviation.

Table 4
Fixed effects structure for the mixed-effects model of RTs in the modified color-shape switching task

Fixed effects	Estimate	SE	*t*
(Intercept)	466.71	8.18	57.08***
Context (single vs. dual)	107.88	8.93	12.08***
Context (color vs. shape)	10.06	7.91	1.27

***$p < .001$.

$= 11.70$, $p < .001$, $d = 0.75$). Moreover, there was no significant RT difference between the color and shape context.

In line with Experiment 1, we assessed the switch and mixing costs. Considering the unequal number of trials between repeat and single trials, only even trials of the single contexts entered the analysis for mixing costs for each participant. Within the dual-context, there was a significant switch cost with slower RTs for switch trials ($M = 570$ ms, $SD = 67$) than repeat trials ($M = 509$ ms, $SD = 66$), $t = 8.42$, $p < .001$, $d = 1.48$. Furthermore, the mixing costs between the repeat trials of dual-context and the single trials were also significant in both the color context ($M = 421$ ms; $t = 8.82$, $p < .001$, $d = 1.41$) and the shape context ($M = 433$ ms; $t = 8.30$, $p < .001$, $d = 0.91$).

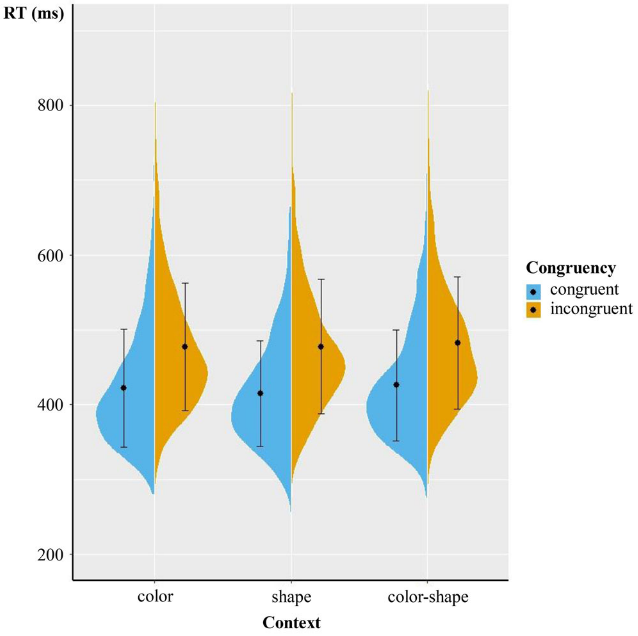

Fig. 6. Split violin plots showing the RTs of the flanker task (Experiment 2) for each control context for each trial type (congruent and incongruent trial). The black dot represents the mean value, while the thin vertical black line represents the standard deviation.

Table 5
Fixed effects structure for the mixed-effects model of RTs in the flanker task of Experiment 2

Fixed effects	Estimate	SE	t
(Intercept)	450.21	7.37	61.12***
Context (single vs. dual)	6.52	5.23	1.25
Context (color vs. shape)	–3.39	6.79	–0.50
Congruency (congruent vs. incongruent)	57.21	4.09	13.98***
Congruency × Context (single vs. dual)	–1.92	4.10	–0.47
Congruency × Context (color vs. shape)	6.95	4.74	1.47

***$p < .001$.

3.2.2. *Flanker task*

The RTs from the flanker task of Experiment 2 are presented in Fig. 6. For the model of RT in flanker task, the fixed effects included Context, Congruency, and their interaction. The random effects included the by-subject random intercept and slopes for Context and Congruency. Table 5 presents the fixed effects structure for the RTs model in flanker task of Experiment 2. Consistent with Experiment 1, participants responded faster to congruent trials ($M = 421$ ms) than incongruent trials ($M = 479$ ms) across three contexts ($t = 13.98$, $p < .001$, $d = 0.62$). However, neither the contrast between single-context and dual-context

($t = 1.25, p = .22, d = 0.07$) nor the contrast between color-context and shape-context reached significance ($t = –0.50, p = .62, d = –0.03$), suggesting the flanker task performance among three contexts was similar (color context: $M = 449$ ms; shape context: $M = 446$ ms; and color-shape context: $M = 454$ ms).

Moreover, we conducted additional correlation analysis for two experiments aiming to further examine if the monitoring process in short-term context task was related with the ensuing conflict monitoring performance in flanker task. The correlation analysis for Experiment 1 between the mixing costs of language switching task and the mean RTs of all flanker trials in the dual-language context showed a significant correlation ($r = .39, p = .04$), whereas the correlation for Experiment 2 was not significant ($r = .06, p = .75$).

3.3. *Discussion*

In sum, Experiment 2 compared the flanker task performance between single- and dual-contexts, but without the need for language processing. In contrast to the effect of language switching in Experiment 1, the general switching between nonverbal stimuli (i.e., color and shape) failed to influence the subsequent flanker task, with similar performance across different contexts.

4. General discussion

By creating different short-term language contexts (i.e., a language switching context vs. single language contexts), Experiment 1 examined the effect of language switching on general monitoring performance (i.e., flanker task) in unbalanced bilinguals. Compared with single L1/L2 contexts, short-term language switching context exerted an immediate effect on subsequent monitoring performance, as evidenced by faster responses to congruent and incongruent flanker trials. Experiment 2 further investigated whether the short-term adaptations of Experiment 1 were due to general switching between visual information by removing language processing demands (i.e., comparing modified color-shape switching context to single contexts). The nonlinguistic color-shape switching context had no impact on flanker task performance. This is in line with a recent study, which showed that switching between linguistic aspects but not low-level visual aspects (i.e., color changes) enhances the efficiency of the domain-general attention system (Timmer et al., 2021a).

The present study contributes in two crucial ways to the literature. First, the present study provided evidence for the effect of bilingual comprehension context on monitoring. After short-term practice in the language switching context, an enhanced monitoring performance was observed as compared to after single-language contexts. To the extent that this reasoning predicts, the long-term experience of language switching in comprehension may increase monitoring efficiency. Second, we showed that this modulation did not occur after nonlinguistic color-shape switching. This suggests that the linguistic component during switching potentially requires deeper processing than low-level switches between colors and shapes, as suggested by Timmer et al. (2021a) in a recent study. The depth of processing might be crucial for consequent domain-general enhancements in monitoring.

In Experiment 1, it is worth noting that the short-term language switching enhancement on the flanker task was observed in both congruent and incongruent conditions, reflecting the engagement of the conflict monitoring mechanism. Most previous studies using language comprehension tasks also found enhanced conflict monitoring during bilingual compared to monolingual contexts (Jiao et al., 2019; Struys et al., 2019; Timmer et al., 2021a, 2021b; but see Wu & Thierry, 2013). Enhanced conflict monitoring during bilingual contexts is in line with the idea that language control is mediated through attentional processes, such as monitoring (Dong & Li, 2020; Timmer et al., 2021a). The reason why our short-term language switching context impacted monitoring performance may be related to the language control demand during comprehension compared to production (Blanco-Elorrieta & Pylkkänen, 2016; Struys et al., 2019; Wodniecka et al., 2020). During the preceding language switching task, bilinguals could not predict the target language (on a trial-to-trial basis) because the two languages were presented randomly. To respond fast and accurately in the language switching task, the monitoring processes are active, enhancing attentional processes that carried over to the flanker task. The short-term nature of these modulations can be taken as a support for the Adaptive Control hypothesis.

Experimental evidence for cross-talk between bilingual language control and executive control in the short term is provided for unbalanced (present study) and balanced bilinguals (Timmer et al., 2021a). This raises the question of how these short-term manipulations are related to long-term daily life effects. The critical role of long-term language switching experience has been shown by Verreyt et al. (2016). They selected three groups of bilinguals (i.e., unbalanced bilinguals, balanced nonswitching bilinguals, and balanced switching bilinguals) based on an individual's long-term bilingual experience. All participants were required to perform a flanker and a Simon task to measure executive control performance. The results showed that balanced bilinguals who often switched between languages outperformed the other two groups in the executive control tasks. In contrast, the unbalanced bilinguals and balanced nonswitching bilinguals did not differ. Long-term enhanced conflict monitoring may result from the need to constantly monitor which language is required to achieve effective communication in a bilingual context (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Timmer et al., 2021a) and may have its origin in short-term exposure to bilingual contexts. However, we need to be cautious about the relationship with long-term daily life effects. Most likely, daily language switching is not as intense as during our language switching training protocol in the experiment.

What is the origin of domain-general monitoring enhancement after being exposed to a bilingual compared to a monolingual situation? Timmer et al. (2021a) revealed that short-term switching between languages and short-term switching between categories (nouns and verbs) within one language enhanced monitoring. However, passive switches of ink color did not show a monitoring enhancement. Therefore, it is not low-level perceptual variability that accounts for the enhancement. The short-term switching context in the study of Timmer et al. (2021a) was passive and did not require any actions. In Experiment 2, we tested whether active switching between colors and shapes did reveal a critical role for domain-general switching on monitoring adaptations. Despite the presence of switch and mixing costs in the context task of Experiment 2, the dual-context did not impact subsequent conflict monitoring performance. The discrepant findings between Experiment 1 and Experiment 2 may be related to the depth of processing. During the modified color-shape switching task of Experiment 2, participants were required to respond to the color/shape information, akin to perceptual processing. In contrast, in Experiment 1, language comprehension might involve deeper processing to access the meaning of each word. Thus, the monitoring system gets enhanced after changes in aspects of higher-order linguistic processing but not after lower-level visual changes (Timmer et al., 2021a, 2021b).

Another possible explanation for our findings could be that the modified color-shape switching task (Experiment 2) might be easier than the language switching task (Experiment 1) as the mean response latencies were shorter for the modified color-shape switching context task than for the language switching context task. Participants probably performed faster in the modified color-shape switching task because the perceptual processing is at a surface level. However, both switch and mixing costs were observed in the modified color-shape switching task. This suggested that the experimental manipulation successfully created executive control demands in the dual context of the modified color-shape task. Furthermore, Experiment 1 only revealed a mixing cost and no switch cost, suggesting the color-shape task could be more difficult. Therefore, it is more likely that the difference in executive control mechanisms than the task difficulty difference between the two experiments explains why modified color-shape switching failed to influence executive control performance. To some extent, the role of language processing in executive control is still an open question worthy of further studies.

Results from the present study showed a relationship between language switching but not nonlinguistic switching and domain-general conflict monitoring. This effect is supported by the significant correlation between preceding mixing costs and mean flanker RTs in Experiment 1 (language processing) and not Experiment 2 (nonlinguistic processing). Enhanced global control, as measured in the mixing cost, shows increased performance in keeping track of a goal (i.e., sticking to one language) (Bobb & Wodniecka, 2013). Global control is closely related to goal maintenance or monitoring measures, which plays an important role in keeping track of changes in the environment (Wodniecka et al., 2020). We acknowledged, however, that our findings based on the relatively small sample size are limited to unbalanced bilinguals, although Timmer and colleagues (2021b) revealed a similar monitoring enhancement with balanced Catalan–Spanish bilinguals. Moreover, another limitation of the present study is that the two experiments employed different groups of unbalanced bilinguals; individual differences are likely worthy of consideration in further research.

5. Conclusion

The present study revealed the impact of a language switching context for a short term on general monitoring performance, which could be taken as a support for the cross-talk between bilingual language control and executive control. Compared with single-language contexts, the language switching context facilitated flanker task performance across congruent and incongruent conditions. However, the color-shape switching context failed to influence executive control performance. These findings suggest that language switching in a comprehension task impacts general monitoring in unbalanced bilinguals, which is closely associated with high-order language switching but not low-order visual switching.

Acknowledgments

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Appendix A

The English and Chinese name of pictures in Experiment 1

Chinese names			English names		
苹果	茶杯	猴子	apple	cup	monkey
胳膊	桌子	月亮	arm	desk	moon
皮球	小狗	山峰	ball	dog	mountain
香蕉	门	老鼠	banana	door	mouse
床铺	裙子	鼻子	bed	dress	nose
自行车	耳朵	橘子	bicycle	ear	orange
小鸟	眼睛	熊猫	bird	eye	panda
书本	手指	梨子	book	finger	pear
盒子	花朵	钢笔	box	flower	pen
面包	脚	铅笔	bread	foot	pencil
公交	女孩	钢琴	bus	girl	piano
蛋糕	眼镜	小猪	cake	glasses	pig
汽车	吉他	兔子	car	guitar	rabbit
扑克	手	尺子	card	hand	ruler
小猫	帽子	星星	cat	hat	star
椅子	房屋	太阳	chair	house	sun
小鸡	钥匙	老虎	chicken	key	tiger
钟表	小刀	火车	clock	knife	train
云彩	小腿	大树	cloud	leg	tree
电脑	地图	手表	computer	map	watch