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Contributions of second language proficiency and interpreting experience to cognitive control differences among young adult bilinguals

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The present study investigates how two important aspects of bilingualism, second language (L2) proficiency and language interpreting experience, contribute to cognitive control differences among young adult bilinguals. By requiring participants to complete the Flanker task (testing inhibition in cognitive control) and the Wisconsin Card Sorting Test (WCST; testing mental set shifting in cognitive control), we compared four groups of Chinese–English bilinguals who varied in L2 proficiency and interpreting experience. The results showed that there was no significant group difference across all groups in the Flanker task. However, in the WCST, although there was no group difference between bilinguals differing in L2 proficiency, there was a significant difference between groups differing in interpreting experience, including groups differing in years of interpreting training. The results indicate that language interpreting experience, as part of bilinguals' language use ecology, significantly contributes to mental set shifting enhancement in cognitive control among young adult bilinguals. The findings motivate further research into the processing mechanism involved in language interpreting.

Keywords: Bilingualism; Cognitive control; L2 proficiency; Language interpreting; Young adult bilinguals.

With the prevalence of bilingualism continuously increasing, there has been an upsurge in the research on bilingualism in the past decades (Bialystok, Craik, Green, & Gollan, 2009; Bialystok, Craik, & Luk, 2012; Bialystok, Martin, & Viswanathan, 2005; Carlson & Meltzoff, 2008; Kroll & Bialystok, 2013). In the early 1920s, there was a belief that learning two languages might cause intellectual and cognitive detriments in childhood (Saer, 1923; Smith, 1923). However, since the 1960s, there has been an optimistic view that bilingualism exerts positive effects on cognitive development (Bialystok et al., 2009; Peal & Lambert, 1962). Many studies have demonstrated that bilinguals have a measurable cognitive control advantage when compared to matched monolinguals (Bialystok et al., 2009, 2012), presumably due to the bilinguals' need to switch between two

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languages and inhibit the potentially activated non-target language in language processing. In order to comprehend or produce the target language successfully, bilinguals adopt a language control system (Green, 1998), which is part of the general cognitive control mechanism,[1] to inhibit the potentially activated non-target language. This experience of continuous inhibition in managing two languages in turn strengthens the general cognitive control mechanism, which, according to Miyake et al. (2000), and Miyake and Friedman (2012), mainly consists of three relevant but independent components: inhibition, shifting and updating. However, it remains to be seen what aspects of bilingualism contribute to this enhancement of cognitive control.

Previous studies indicated that cognitive control advantages (either inhibition, shifting, updating, or monitoring, or some combination of these components) have been detected in bilinguals of various ages. For example, Bialystok, Barac, Blaye, and Poulin-Dubois (2010) found that child bilinguals (3–4.5 years) showed cognitive control superiority over their age-matched monolingual peers. Similarly, Bialystok, Craik, and Freedman (2007) found that older adult bilinguals (78.6 years) showed delayed cognitive decline compared to their monolingual counterparts (75.4 years). In addition, young adult bilinguals (20–30 years) have also shown cognitive advantages relative to monolinguals (Bialystok, 2009; Costa, Hernandez, Costa-Faidella, & Sebastian-Galles, 2009; Prior & Gollan, 2011; Prior & Macwhinney, 2010). Apart from behavioural measures, functional and structural neuroimaging studies (Abutalebi et al., 2012) showed that the dorsal anterior cingulate cortex (ACC), a structure tightly bound to domain-general cognitive control functions, is a common locus for language control and for resolving non-verbal conflict. This provides a neural and anatomical basis for the interactions between linguistic control and non-linguistic control. However, not all studies have actually identified such a bilingual advantage, particularly in behavioural measures when testing young adult bilinguals (Bialystok, Luk, Peets, & Yang, 2010; Bialystok et al., 2005; Kousaie & Phillips, 2012; Luk, Anderson, Craik, Grady, & Bialystok, 2010; Paap & Greenberg, 2013; Paap & Liu, 2014). The reasons for this discrepancy are still being debated. A variety of factors have been proposed (see e.g., Kroll & Bialystok, 2013) that may modulate processing differences on cognitive control, including participants' age (as illustrated earlier), task difficulty (e.g., Bialystok, Craik, & Ryan, 2006), individual differences (Festman, Rodriguez-Fornells, & Munte, 2010), language similarities (van Heuven, Conklin, Coderre, Guo, & Dijkstra, 2011) and language contexts (Green, 2011).

However, little empirical work has been done investigating general cognitive control differences *among bilinguals* or the reasons underlying these differences. Generally speaking, factors that can explain cognitive control differences among bilinguals are most probably factors that can also explain cognitive control differences between bilinguals and monolinguals. The first potential factor is second language (L2) proficiency. Is it possible that bilinguals' cognitive control enhancement is related to their L2 proficiency, as L2 proficiency varies among L2 learners? Videsott, Della Rosa, Wiater, Franceschini, and Abutalebi (2012) suggest that proficiency levels in early multilingual children may play a crucial role in the development and enhancement of the alerting component of the attentional system in cognitive control. In other studies, language proficiency has been reported relevant to cognitive control performance on tasks requiring conflict resolution and goal maintenance (Tse & Altarriba, 2012), on tasks requiring inhibition (Singh & Mishra, 2012, 2013) and on tasks requiring inhibition and shifting (Iluz-Cohen & Armon-Lotem, 2013). However, language proficiency, as a complex construct (Hulstijn, 2012), generally does not reveal what degrees of proficiency may lead to better cognitive control. Furthermore, as bilinguals' language proficiency increases, other confounding factors (such as increased language switching and language use in a particular pattern) might obscure the effect. Therefore, in the current study, one of the goals is to further examine the relationship between L2 proficiency and cognitive control in bilinguals in conjunction with other potential factors.

The most probable potential factor among young adult bilinguals is their particular language use patterns. Bilinguals may vary in how they use their languages and in how they use the languages in different community contexts (Green, 2011; Prior & Gollan, 2011). According to Green (2011), the community context in which bilingual speakers typically use their two languages (the behavioural ecology of bilingual speakers) should be adequately considered in the study of bilingual

[1] The terms 'executive processing', 'executive functioning' or 'executive control' are used more or less as synonyms in the literature.

advantage. More recently, the adaptive control hypothesis (Green & Abutalebi, 2013) has proposed that language control processes themselves adapt to the recurrent demands placed on them by the interactional context. Adapting a control process means changing a parameter, or the parameters, concerning the way it works (its neural capacity or efficiency), or the way it works in concert, or in cascade, with other control processes (e.g., its connectedness). Therefore, the different contexts (such as a single or dual language context or an intensive language switching context) that require different cognitive demands may very likely lead to varied control adaptations.

Our second goal is thus to focus on the language use context of interpreting, which involves intensive and intentional switching between the two languages. Although a few studies have found some relationship between how frequently bilinguals switch their two languages in their daily life and their cognitive control abilities (Prior & Gollan, 2011; Rodriguez-Fornells, Kramer, Lorenzo-Seva, Festman, & Munte, 2011; Soveri, Rodriguez-Fornells, & Laine, 2011), the task of interpreting involves a more intensive experience of language switching and therefore provides a good context to study bilingual control (De Groot & Christoffels, 2006). There have been studies indicating that, compared to reading in the monolingual mode, the task of interpreting requires more activation of both languages while comprehending the source language (e.g., Dong & Lin, 2013; Yudes, Macizo, Morales, & Bajo, 2012), and that the interpreter has to put great effort into coordinating both comprehension and production in the process of interpreting, especially simultaneous interpreting[2] (e.g., Padilla, Bajo, & Macizo, 2005; Yudes, Macizo, & Bajo, 2012). These particular features inherent in the interpreting task pose a special demand on language control to monitor, coordinate and separate the two languages during comprehension and production while continuously switching between them (Ibanez, Macizo, & Bajo, 2010). Interpreting training, with this higher demand, may thus enhance the efficiency of language control and eventually transfers to non-verbal tasks. Yudes, Macizo, and Bajo (2011) found that professional simultaneous interpreters outperformed control bilinguals and monolinguals in the cognitive control function of mental flexibility. In their study, a Simon task (which tested inhibition) and a Wisconsin Card Sorting Test (WCST) (which tested shifting) were adopted. The results revealed that professional interpreters did not perform differently from control bilinguals and monolinguals in the Simon task, but outperformed bilinguals and monolinguals on the WCST, which suggests that experience in interpreting is associated with cognitive flexibility (mental set shifting) in cognitive control.

To sum up, L2 proficiency and language interpreting experience are probably two crucial aspects of bilingualism that affect cognitive control. The main purpose of the current study is thus to identify how the two important factors, L2 proficiency and language interpreting experience, contribute to cognitive control differences among young adult bilinguals. Our research rationale is as follows: (1) If L2 proficiency plays a significant role in cognitive control enhancement, bilinguals who differ in L2 proficiency may perform differently in cognitive control tasks when other factors are controlled. (2) If language interpreting experience plays a crucial role, bilinguals with or without such experience may perform differently in cognitive control tasks when other factors are controlled. To find an answer to these questions, we compared four groups of unbalanced Chinese–English bilinguals who differed in L2 proficiency and language interpreting experience (see the Participants section for details). The participant groups were compared in terms of their performance on the Flanker task and the WCST. These tasks were selected in light of the theoretical construct of executive control, as proposed by Miyake and colleagues (Friedman & Miyake, 2004; Miyake & Friedman, 2012; Miyake et al., 2000). As mentioned earlier, three relevant but independent components of executive control were identified: inhibition, mental set shifting and working memory updating. Inhibition is the capacity to supersede responses that are prepotent in a given situation. Shifting is the cognitive flexibility

[2] The two typical modes of interpreting are consecutive interpreting, in which the interpreter immediately begins the interpretation of a message after the speaker has stopped speaking, and simultaneous interpreting, in which the interpreter renders the interpretation while still receiving the source utterance. Apparently, the latter is cognitively more demanding, since the interpreter has to split his or her attention and exercise a tighter control of the whole process so that comprehension and production are well coordinated. Another form of intensive language switching experience is (written) translation. Since the task of translation generally does not require immediate rendition, it does not pose as much demand on language control as interpreting. And yet, the three forms of language switching experience all involve basically the same switching process, intensive switching between the two languages.

to switch between different tasks or mental states. Updating is defined as the continuous monitoring and quick addition or deletion of contents within one's working memory. We assessed the aspects of inhibition and mental set shifting in the current study, since these abilities have been reported to be primarily enhanced in bilingualism in the literature. For this purpose, the Flanker task was designed to test participants' inhibition, and the WCST was designed to measure participants' mental set shifting.

METHODS

Participants

One hundred and fifty-four Chinese–English right-handed adult bilinguals (14 males/140 females) from Guangdong University of Foreign Studies, and with a mean age of 21.58 years (standard deviation [*SD*] = 1.545), participated in this study for either financial compensation or course credit. All of them reported normal or corrected-to-normal vision and had no speech or hearing disorders. They gave informed consent, and their rights were protected in accordance with the ethical standards of the university's Academic Board.

There were four groups of participants: two with language interpreting experience, coded hereafter as Interpreting-1 and Interpreting-2, and two without language interpreting experience, coded as Noninterpreting-1 and Noninterpreting-2. The interpreting groups were undergraduate or graduate students specialising in translation and interpreting studies in the university, with Interpreting-1 having received interpreting training for one year (tests taken at the end of third-year undergraduate studies), and Interpreting-2 for three years (tests taken at the end of first-year graduate studies). The non-interpreting groups, as controls for the interpreting participants, were students majoring in general English (English language and culture) who had received no formal training on language interpreting before participating in this study. The interpreting groups took special courses, such as consecutive interpreting, translation, conference interpreting, interpreting workshops, etc., which could be classified as language switch training. There were four such courses for each semester of about 18 weeks (two semesters in a year), with each course taking 80 min per session each week. After-class practice was generally required, amounting to about 8–16 hr each week. When Interpreting-1 participated in our study, they had taken eight such courses (half interpreting, half written translation[3]), amounting to 192 hr of class time in total. The class time for the group of Interpreting-2 was triple that of Interpreting-1.

All participants' previous experience with English (L2) was homogeneous in that they had started learning English as a foreign language (in the classroom) around age 10, in order to qualify for college enrolment. This suggests that the participants were unbalanced bilinguals who had few L2 communication needs in their everyday life (with English mostly used in classes of English, or when watching English videos or reading English books outside the classroom). To assess language proficiency, we required the participants to complete a composite questionnaire with questions tapping participants' language background, including self-rated language proficiency (Marian, Blumenfeld, & Kaushanskaya, 2007), and to perform an English (L2) verbal fluency test as an objective measurement. In the verbal fluency test, participants were required to produce as many words as possible according to the category presented (jobs, sports, animals) in 60 seconds. Category fluency is reported to be strongly indicative of vocabulary size (Bialystok et al., 2009).

Table 1 is a summary of the participants' characteristics.[4] As can be seen there, the four

[3] The current study does not try to isolate the interpreting experience from that of translation, since interpreting and translation basically involve the same language switching process (as stated in footnote 2), and students receiving interpreting training generally receive translation training at the same time, although the reverse is not necessarily true.

[4] We did not assess participants' socio-economic status (SES) and intelligence quotient (IQ) because we believed they were not so much relevant to our participants in the present study. Although Hook, Lawson, and Farah (2013) suggested an association between SES and cognitive control, this association is mostly based on child bilinguals (but see Prior & Gollan, 2011). Furthermore, the participants in the present study came from similar family background. Thus, we assumed that there was no systematic SES bias across the groups. As for IQ, since our participants were admitted to the same university after taking the same college entrance examination, it is unlikely that there were systematic IQ differences among the different participant groups. In addition, some previous studies showed that working memory updating was highly correlated with intelligence measures, but inhibiting and mental set shifting tested in the present study were not (Friedman et al., 2006; Toplak, Sorge, Benoit, West, & Stanovich, 2010).

TABLE 1
Characteristics of the four groups of participants

	Noninterpreting-1 n = *45*	*Noninterpreting-2* n = *43*	*Interpreting-1* n = *46*	*Interpreting-2* n = *20*
Age (years)	20.5[a] (0.8)	22.4[b] (1.8)	21.1[c] (0.9)	23.3[d] (1.2)
Learning history (years)	10.5[a] (0.8)	12.4[b] (1.7)	11.1[c] (0.9)	13.3[d] (1.2)
English proficiency (0–40)	21.5[a] (2.7)	23.2[b] (4.5)	22.9[b] (3.4)	29.8[c] (3.3)
English verbal fluency	19.4[a] (3.7)	24.4[b] (4.2)	24.9[b] (4.0)	30.5[c] (5.0)
English exposure (%)	47.8 (21.5)	43.3 (17.7)	41.5 (16.2)	48.3 (16.6)
English use (%)	20.3[a] (6.0)	21.3[a] (5.7)	21.9[a] (6.9)	29.3[b] (7.0)
Interpreting training (years)	None	None	1	3

Means in the same row with different superscript letters differ from each other significantly at $p < .01$ or $p < .05$.

groups differed in L2 proficiency at three levels.[5] Interpreting-2 had the highest English proficiency, which differed from the other groups (*p*s < .001); Interpreting-1 and Noninterpreting-2 were matched in L2 proficiency ($p = .608$); and Noninterpreting-1 had the lowest language proficiency (*p*s < .001). At the same time, all the groups had the same percentage of English (L2) exposure (Chinese and English equals 100%; *p*s > .05). However, Interpreting-2 had the highest percentage of English (L2) use (*p*s < .0001), whereas Interpreting-1, Noninterpreting-2 and Noninterpreting-1 did not differ (*p*s > .05).

Materials and procedure

Two computerised tasks (the Flanker task and the WCST) were used to tap participants' cognitive control in inhibition and mental set shifting, respectively.

Flanker task. The Flanker task (Eriksen & Eriksen, 1974), used to assess the ability to suppress responses that are inappropriate in a particular context, was designed as described in previous studies (Festman & Munte, 2012; Luk et al., 2010). Participants were instructed to respond to the direction of a red target chevron flanked by symbols. There were three conditions for the different trials. On neutral trials, the flanking symbols were four black diamonds providing no information that interfered with the target chevron. On congruent trials, the red target chevron was flanked by four black chevrons pointing in the same direction as the target. On incongruent trials, in contrast, the four flanking chevrons pointed in the direction opposite, creating conflict. In the computerised procedure, each trial started with a '+' fixation for 250 ms. Then, a randomly selected stimulus was presented for 2,000 ms. The stimulus disappeared when participants responded (by key press) or after 2,000 ms had elapsed. Participants did not begin formal trials (108 trials) until reaching a correction rate above 80% on practice trials (9 trials), which was taken as an indication of focused attention on the task. The experiment was programmed with the E-Prime (version 2.0) software.

By using the Flanker task, we expected to find out which bilingual group might be better/faster at inhibiting distracting information, focusing on the target stimulus and superseding any unwanted response. The advantage at inhibition in the Flanker task, which makes minimal demands on language processing, is evidence of superior non-linguistic cognitive control. We thus hoped to see either performance differences between groups with differing L2 proficiency or between groups with differing language interpreting experience, or both.

WCST. The WCST, used to detect participants' ability to switch their mental set and their flexibility to infer the sorting rule, was adapted from Yudes et al. (2011). There were altogether 128 response cards and 4 stimulus cards depicting different dimensions of geometric figures. There were three dimensions: shape (triangle, star, cross or circle), colour (red, green, yellow or blue) and number (one, two, three or four). The three dimensions were combined to sort the response card according to the dimension of four stimulus cards (the four stimulus cards depicted one red

[5] Only English proficiency was assessed. This is based on our presumption that our participants, who had passed a college entrance examination and were regular college students majoring in English or interpreting, must have concurrently maintained a high proficiency in their native language – Mandarin Chinese. We believe that there was no significant difference in their L1 proficiency (although there might be variations) due to the homogeneity of their educational background.

triangle, two green stars, three yellow crosses and four blue circles). After sorting the response cards (by key press), the participants received feedback on whether their responses were correct. However, the sorting rule changed after a few trials, and participants were not informed about the underlying rule. In the computerised version used here, there were 12 practice trials in the first block, and 128 formal trials in the second. There was a '+' fixation for 1,000 ms before the stimulus was presented. The stimulus lasted for no more than 3,000 ms, during which time participants had to respond by pressing designated keys (one key for each dimension). Participants would receive feedback (1,000 ms) on their responses ('correct' or 'incorrect') and were asked to continue sorting until all 128 cards were finished. Participants knew that the sorting rule would change after a few trials (from 5 to 9) but did not know what the rule was or when it would change. This task was programmed with the E-Prime, same software.

According to Miyake et al. (2000), the WCST involves shifting back and forth between multiple tasks, operations or mental sets, which is also referred to as attention switching or task switching. This executive function seems crucial in understanding failures of cognitive control, both in brain-damaged patients and in healthy participants in laboratory tasks that require shifting between tasks (Friedman & Miyake, 2004; Miyake et al., 2000). The WCST as described earlier is similar to language switching in interpreting because both task switching and language switching involve the underlying mechanism of mental set shifting. We expected that the groups with language interpreting experience would perform better than the control groups, and we also wanted to know whether participants of higher L2 proficiency would outperform those of lower L2 proficiency.

RESULTS

Data trimming

The final data set was created in the following way: In the Flanker task, data from erroneous responses were first excluded. We then calculated the mean reaction time (RT) and the *SD* of each subject in each condition, and eliminated trials that were over 3 *SD*s above the mean (with a final data loss of 1.87% of all trials). In the WCST, we first calculated the mean RT for each of the subjects in each condition, and excluded trials that fell 3 *SD*s above or below the mean (1.32% of all trials). We then counted the characteristic indexes of the WCST for each participant, including completed categories, overall errors and types of errors.

Flanker task

Table 2 is a summary of the descriptive data for the Flanker task. The dependent variables are the overall mean RTs in each condition and the Flanker conflict. To determine whether the bilingual groups of higher proficiency would complete the task more efficiently than the bilingual groups of lower proficiency and whether the language interpreting groups would outperform the non-interpreting groups, we conducted a repeated measures analysis of variance (ANOVA), with participant groups (Interpreting-1, Noninterpreting-1, Interpreting-2, Noninterpreting-2) as a between-subjects variable and condition (neutral, incongruent, congruent) as a within-subject variable.

The analysis revealed a significant main effect of trial condition, $F(2, 300) = 151.246$, $p < .001$, $\eta^2 = .502$. Pairwise comparisons showed that participants responded more quickly in the congruent condition (518 ms) than in the neutral (535 ms) and incongruent conditions (573 ms; *p*s < .001), and participants responded more quickly in the neutral condition (535 ms) than in the incongruent condition (573 ms; $p < .001$), reflecting a significant Flanker effect (difference between congruent and incongruent condition). However, the analysis revealed no main effect of participant group, $F(3, 150) = .553$, $p = .647$, and the interaction between participant group and Flanker condition was not significant, $F(6, 300) = .496$, $p = .811$, indicating that there was no group difference in the speed and efficiency in responding to the three conditions of the Flanker task. Moreover, an ANOVA showed that there was no group difference in terms of Flanker conflict (RTs difference between congruent and incongruent condition) across groups, $F(3, 150) = .641$, $p = .590$, suggesting that the four groups did not differ in conflict resolution when congruent and incongruent trials were mixed.

The four groups differed both in L2 proficiency and in language interpreting experience. As can be seen in Table 1, Interpreting-2 had the highest L2 proficiency and also used the L2 the most

TABLE 2
Means (*SD*s) of RTs and Flanker conflict in the Flanker task across groups

	Noninterpreting-1 n = *45*	*Noninterpreting-2* n = *43*	*Interpreting-1* n = *46*	*Interpreting-2* n = *20*
Flanker neutral	543 (103)	536 (91)	533 (76)	518 (90)
Flanker incongruent	583 (111)	578 (87)	569 (83)	548 (67)
Flanker congruent	528 (119)	516 (81)	518 (73)	497 (86)
Flanker conflict[a]	55 (36)	62 (50)	51 (33)	51 (35)

[a]Flanker conflict refers to the RT difference between incongruent and congruent conditions.

(which differed from the other groups with *p*s < .001); Interpreting-1 and Noninterpreting-2 were homogeneous in L2 proficiency with $p = .608$; and Noninterpreting-1 had the lowest L2 proficiency (*p*s < .001). However, there was no difference across groups, either in speed or in conflict resolution, on the Flanker task (see Table 2). We further ran analyses comparing only two levels, namely interpreting vs. non-interpreting, with L2 proficiency (verbal fluency scores) as a covariate. The results neither showed any significant effect of interpreting experience on overall RTs of the three trial types nor on the Flanker conflict (Flanker neutral: $F < 1$, $p = .804$; Flanker incongruent: $F < 1$, $p = .816$; Flanker congruent: $F < 1$, $p = .948$; Flanker conflict: $F < 1$, $p = .530$). In short, the results indicate that, in terms of RTs and conflict resolution, neither L2 proficiency nor language interpreting experience played a significant role in distinguishing the ability of inhibition in cognitive control across the bilingual groups.

Wisconsin Card Sorting Test

Global performance (RTs, completed categories, overall errors) and different types of errors (perseverative errors, previous category errors) are reported as dependent variables to compare performance differences in mental flexibility (Barceló & Knight, 2002) across the groups. Table 3 presents the means and *SD*s of RTs, completed categories, overall errors, perseverative errors and previous category errors across groups.

Global performances. The ANOVA of *global RTs* showed that there was no significant difference between the groups, $F(3, 150) = .628$, $p = .598$. The total number of categories ranged from 0 (which means the participant was unable to complete at least five consecutive correct responses to any of the categories) to 19 (which means the participant successfully completed all the categories). The results of ANOVA on the number of *completed categories* showed that there were significant differences across the groups, $F(3, 150) = 7.798$, $p < .001$, $\eta^2 = .135$. Post hoc analyses showed that Interpreting-2 completed the highest number of categories compared to the two non-interpreting groups (Noninterpreting-1: $p < .001$; Noninterpreting-2: $p < .001$). Moreover, between the two interpreting groups, Interpreting-2, who had had a longer language interpreting experience, higher L2 proficiency and more L2 use, completed significantly more categories than Interpreting-1 ($p = .048$). In addition, Interpreting-1, similar to Interpreting-2, completed a higher number of categories compared to Noninterpreting-1 ($p = .006$) and Noninterpreting-2 ($p = .013$). However, there was no group difference between the two non-interpreting groups ($p = .819$), who differed in L2 proficiency. The ANOVA on the *overall errors*

TABLE 3
Means (*SD*s) of RTs, completed categories, errors, etc. in the WCST by language group

	Noninterpreting-1 n = *45*	*Noninterpreting-2* n = *43*	*Interpreting-1* n = *46*	*Interpreting-2* n = *20*
Global RTs	1426 (433)	1556 (526)	1450 (490)	1504 (439)
Completed categories	9.0[a] (3.5)	9.2[a] (3.4)	11.0[b] (3.3)	12.8[c] (3.4)
Overall errors	60.1[a] (14.9)	57.7[a] (14.1)	47.8[b] (11.2)	43.0[b] (12.7)
Perseverative errors	39.8[a] (17.0)	37.3[a] (15.3)	26.2[b] (10.7)	21.9[b] (14.3)
Previous category errors	22.0[a] (15.9)	19.9[a] (13.1)	11.8[b] (8.0)	8.2[b] (8.1)

Means in the same row with different superscript letters differ from each other significantly at $p < .01$ or $p < .05$.

revealed a significant difference across groups, $F(3, 150) = 12.051$, $p < .001$, $\eta^2 = .194$. Post hoc multiple comparisons showed that both Interpreting-1 and Interpreting-2 made fewer errors than Noninterpreting-1 and Noninterpreting-2 ($p = .001$, $p < .001$, respectively). However, there was no group difference between the two interpreting groups ($p = .179$) or between the two non-interpreting groups ($p = .395$; see Table 3).

Types of errors. Heaton et al. (1993) distinguish between perseverative and non-perseverative errors. Perseverative errors represent failures to change the mental rule after receiving negative feedback, so that the test candidate continues sorting the cards according to the previous category dimension, despite feedback indicating that the response has been wrong (Heaton et al., 1993; Yudes et al., 2011). In addition, the errors can be further categorised into perseverations of the immediately preceding category and perseverations of a different category (Hartman, Steketee, Silva, Lanning, & Andersson, 2003; Yudes et al., 2011). Previous category perseverations reflect a lack of flexibility in changing the mental set to a new rule, whereas different category perseverations reflect the understanding that the previous rule is no longer correct, but there has been an unsuccessful attempt to infer a new rule. An ANOVA was conducted to examine the distribution of these types of errors in each group. The ANOVA results of *perseverative errors* showed significant differences across the groups, $F(3, 150) = 11.784$, $p < .001$, $\eta^2 = .191$. Further post hoc multiple comparisons indicated that the two interpreting groups made fewer perseverative errors than the two non-interpreting groups ($ps < .001$). However, there was no group difference between the two interpreting groups ($p = .265$) or between the two non-interpreting groups ($p = .420$). The ANOVA performed on the number of *previous category errors* revealed a significant group effect, $F(3, 150) = 9.527$, $p < .001$, $\eta^2 = .160$, with post hoc analyses indicating that Interpreting-2 made fewer previous category errors than the two non-interpreting groups ($ps < .001$), and that Interpreting-1 also made fewer such errors than the two non-interpreting groups ($p = .002$, $p < .001$). However, there was neither any difference between the two interpreting groups ($p = .269$) nor between the two non-interpreting groups ($p = .434$; see Table 3).

Further analyses. To provide further support for the contrast between interpreting experience and L2 proficiency, we divided Interpreting-1 into two subgroups: one with higher L2 proficiency (20 participants) and the other with lower L2 proficiency (26 participants), so that we had a group of participants who were different from Interpreting-2 in the years of interpreting training they had received, but at the same level of L2 proficiency (verbal fluency; $p = .131$). The two interpreting groups (Interpreting-1-subgroup and Interpreting-2), comparable in L2 proficiency, were different in completed categories in WCST ($p = .039$), and the differences between the two groups in overall errors and previous category errors were marginally significant ($p = .077$, $p = .069$, respectively), but without any group differences in overall RTs and perseverative errors (see Table 4). In other words, whereas there were differences in some of the WCST indices between the two groups of participants with different years of interpreting training, the contrast between these two groups was not as sharp as the contrast between those who had received interpreting training and those who had not. This is robust support for the role of

TABLE 4
Characteristics of Interpreting-1 subgroup and Interpreting-2 and their performances in the WCST

	Interpreting-1-subgroup n = *20*	*Interpreting-2* n = *20*	p *Value* (t-*test*)
English verbal fluency	28.7 (1.1)	30.5 (5.0)	.131
English exposure (%)	48.3 (16.6)	50.4 (15.8)	.677
English use (%)	22.8 (8.4)	29.3 (7.0)	.011
Global RTs	1346 (371)	1504 (438)	.226
Completed categories	10.4 (3.9)	12.8 (3.4)	.039
Overall errors	50.1 (12.2)	43.0 (12.7)	.077
Perseverative errors	28.0 (10.6)	21.9 (14.3)	.130
Previous category errors	13.2 (9.0)	8.2 (8.1)	.069

language interpreting experience in cognitive control enhancement, that is, the mental set shifting measured in the WCST.

However, this does not exclude the contribution of the factor of L2 use, since Interpreting-2 had also reported a higher percentage of L2 use (p = .011) whereas Interpreting-1-subgroup and Interpreting-2 were matched on L2 proficiency and L2 exposure (see Table 4). In order to further sort out which factor(s) may have contributed significantly to the mental set shifting advantage for the interpreter bilinguals, we conducted a stepwise multiple regression analysis. L2 proficiency (verbal fluency scores), L2 use and L2 exposure were measured as continuous variables, whereas interpreting experience was classified into three levels with '0' representing no interpreting experience, '1' representing one year's interpreting training and '2' representing three years' interpreting training. The results showed that L2 proficiency, L2 exposure and L2 use did not significantly predict bilinguals' performances in the WCST (Fs < 1, ps > .10), but interpreting experience did: completed categories, adjusted R^2 = .125, $F(1, 149) = 22.429$, $p < .001$; overall errors, adjusted R^2 = .172, $F(1, 149) = 32.071$, $p < .001$; preservative errors, adjusted R^2 = .167, $F(1, 149)$ = 31.018, $p < .001$; and previous category errors, adjusted R^2 = .140, $F(1, 149) = 25.502$, $p < .001$.

Summary. To provide a clearer view for the role of interpreting experience and L2 proficiency, we now summarise the contrasts.[6] First, Interpreting-1 and Noninterpreting-2 were matched on L2 proficiency (both in self-rated and in objective measures), L2 exposure and L2 use but differed in language interpreting experience. The ANOVA results of the WCST revealed that Interpreting-1 performed significantly better than Noninterpreting-2 on completed categories, overall errors, perseverative errors and previous category errors (see Table 3). Second, between the two noninterpreting groups, who did not have any interpreting experience and who differed in L2 proficiency, there were no significant differences on any of the dependent variables we examined (completed categories, overall errors, perseverative errors and previous category errors). Third, between the two interpreting groups that differed in years of interpreting training, there were significant differences in some of the WCST indices when L2 proficiency was matched. Fourth, regression analysis revealed no effect for L2 proficiency (or L2 use or L2 exposure) but a significant effect for interpreting experience. To sum up, the WCST results showed that there were robust differences between groups differing in language interpreting experience but no significant differences between groups differing in L2 proficiency.

DISCUSSION

Our research question was how L2 proficiency and language interpreting experience contribute to cognitive control differences among young adult bilinguals. The experimental results revealed that, for young adult bilinguals, L2 proficiency did not contribute to cognitive control differences either in inhibition or in mental set shifting as measured respectively through the Flanker task and the WCST in the current study, whereas language interpreting experience significantly contributed to cognitive control differences in mental set shifting but not in inhibition.

The fact that we did not find any contribution of L2 proficiency in cognitive control advantages runs contradictory to findings from a few previous studies with children (Iluz-Cohen & Armon-Lotem, 2013; Videsott et al., 2012) or young adults (Singh & Mishra, 2012, 2013; Tse & Altarriba, 2012). This may be attributed to a few reasons. First, similar to Bialystok et al.'s (2009) explanation that bilingualism offers no further boost for young adults who are at the peak age of their cognitive capacities (Bialystok, Craik, & Luk, 2008; Bialystok et al., 2005; Paap & Greenberg, 2013; Salvatierra & Rosselli, 2011), higher L2 proficiency may not always bring about more cognitive control advantages in young adults. Second, the presence or absence of cognitive control advantages may be related to task difficulty, such as to what extent the task demands one's attention (Costa et al., 2009). The current study did not reveal any group differences in the Flanker task, probably because the task was too easy for the young adults. Third, L2 proficiency is a very complex concept, which is hard to measure

[6] We noticed that there were significant age differences across all the four groups. However, the factor of age difference was ignored in our analysis because all the participants could be categorised as young adult bilinguals and were in their prime of cognitive control abilities. Moreover, even if this age difference played a significant role in our study, the results would be that the group of Interpreting-2 should be the slowest performers (since they were the oldest), which is obviously contradictory to our findings.

and isolate from factors such as L2 use, L2 experience, etc. The improvement of L2 proficiency is probably accompanied by more L2 use or more language switching experience (especially in a specific context). In addition, it is difficult to define how much language proficiency is needed before a cognitive control advantage shows up in behavioural measures. A larger language proficiency gap may be able to produce significant cognitive control differences among bilingual groups. Moreover, higher L2 proficiency may result in a more balanced use of the two languages, which in turn may lead to more cognitive control advantages (Zied et al., 2004). Apparently, though, the participants in the current study were unbalanced L2 learners.

As for the role of language interpreting experience, we found that bilinguals with language interpreting experience performed significantly better than bilinguals without such experience in mental set shifting (as tested in the WCST) when L2 proficiency was controlled. Even between the two proficiency-matched interpreting subgroups, who had received interpreting training for different lengths of time (1 year and 3 years), there were significant or marginally significant differences in the WCST indices (see Table 4). This result is consistent with previous findings that bilinguals outperform monolinguals in the WCST, or similar tasks, since bilinguals have much experience of switching between the two languages, whereas monolinguals have none (Bialystok, 1999; Bialystok & Martin, 2004; Taler, Johns, Young, Sheppard, & Jones, 2013). The result is also consistent with Yudes et al. (2011), which found that professional interpreters outperformed bilinguals and monolinguals in the WCST.

Although the current study is similar to Yudes et al. (2011) in a number of respects, it also differs from it in certain ways. Yudes et al. (2011) aimed at exploring cognitive control processes in simultaneous interpreters and thus compared how three groups of participants (simultaneous interpreters, bilinguals without simultaneous training and monolinguals) performed in the WCST and Simon task. In contrast, the current study aimed at exploring what roles language interpreting experience and L2 proficiency may play in cognitive control variations among unbalanced bilinguals and thus compared how bilinguals differing in interpreting experience and L2 proficiency performed in the WCST and Flanker task. The first difference between the two studies is that, in Yudes et al. (2011), monolinguals were included, and language proficiency was controlled, whereas in the current study monolinguals were not included and proficiency was manipulated. The second difference is that, in Yudes et al. (2011), a Simon task was used to capture response inhibition, whereas in the current study the Flanker task was used to capture inhibition of a distracting stimulus. The third difference is that, in Yudes et al. (2011), the bilinguals were more or less balanced in the two languages, and the professional simultaneous interpreters had around 10.83 years of interpreting experience, whereas in the current study, the bilinguals were unbalanced, and the student interpreters had only had 1 year or 3 years of interpreting training. Hence although the two studies are similar and yield similar results, they both contribute to the literature by manipulating vs. controlling L2 proficiency and exploring the role of different types of inhibitory control, as well as the role of different lengths of time in interpreting experience. The fact that the pattern of results is similar in the two studies provides further evidence for the general conclusion that language interpreting experience significantly contributes to cognitive control differences in mental set shifting but not in inhibition. Particular contributions from the current study are findings for the comparison of different lengths of interpreting training time (1 year vs. 3 years) and for the comparison between interpreting experience and L2 proficiency, which again provide further support for the general conclusion.

The current study focuses on the two probably most important aspects of bilingualism that are considered relevant to bilingual advantages, that is, L2 proficiency and language switching experience (or to be more specific, interpreting experience). L2 proficiency may be a factor that can enhance cognitive control abilities although it was absent in the current study. But taking all the relevant studies into consideration, it seems that, for young adult bilinguals, the specific experience of interpreting training is a more powerful factor in mental set shifting enhancement. There is evidence indicating that switching between languages increases pre-Supplementary Motor Area/ACC response, regardless of the proficiency differences of the two languages that bilinguals have acquired (Abutalebi et al., 2013). As to why language switching experience enhances cognitive control abilities, relevant research illustrates that language switching leads to the recruitment of brain regions of the left inferior frontal cortex, the caudate and the anterior cingulate among bilinguals (Garbin et al., 2010, 2011), which overlap with the regions responsible for non-linguistic cognitive control. This overlap of brain regions has led researchers to speculate that the continuous employment of these regions in language switching strengthens the capability and increases the efficiency of related brain functions in non-linguistic domains. But then why is it that the student interpreter bilinguals did not outperform their non-interpreter counterparts regarding inhibition? According to Yudes et al. (2011), the experience in interpreting does not necessarily improve all the aspects of cognitive control because the nature of interpreting seems to be independent of the type of inhibition required by tasks such as the Simon and Flanker tasks. Interpreting does not require inhibition, since the two languages are kept active for comprehension and production, but the mental flexibility to switch from one language to another is crucial (Ibanez et al., 2010; Yudes et al., 2011).

If all confounding factors are controlled, a test of the role of potential factors in cognitive control differences *among* young adult bilinguals is a more delicate test of bilingual advantages than a direct comparison between bilinguals and monolinguals. If significant effects for these potential factors can be found among young adult bilinguals, these effects are most likely to appear in the same tests when bilinguals and monolinguals are compared, although the *absence* of such effects among bilinguals does not necessarily mean an absence of bilingual advantages when bilinguals and monolinguals are compared. Since the current study was interested in identifying how L2 proficiency or interpreting experience contributes to cognitive control differences among young adult bilinguals, we did not test a group of monolingual Chinese,[7] which, on the one hand, prevents us from concluding that L2 proficiency is not related to cognitive control advantages, but, on the other, does not prevent us from making the assumption that participants' interpreting experience is an important factor in cognitive control enhancement (in mental set shifting). The current study therefore represents part of the effort to explore whether and how specific bilingual language use experience affects general domain cognitive control enhancement among bilinguals. Future research may include more typical patterns of bilingual language use experience and wider coverage of the bilingual population including, for example, child bilinguals who grow up with two or more languages in their homes. Another line of further research is to see how distinction of experiences with translation, consecutive and simultaneous interpreting, may lead to differences in different aspects of cognitive control, which in turn may help explore the exact nature of interpreting training as described in the current study and its connection with cognitive advantages.

[7] It is in fact impossible to find pure monolingual Chinese who are comparable to Chinese–English bilinguals in an educational background. Some foreign language, mostly English, is compulsory at least starting from junior middle school, with at least four classroom hours every week in school.

CONCLUSION

The present study investigated how the two important aspects of bilingualism, L2 proficiency and language interpreting experience, may contribute to cognitive control differences among young adult bilinguals. The results demonstrated that L2 proficiency does not contribute significantly to cognitive control differences, either in inhibition or in mental set shifting. However, the results also indicate that language interpreting experience, as part of the bilinguals' language use ecology, significantly contributes to cognitive control enhancement in mental set shifting in young adult bilinguals. Interpreting training is an intensive form of language switching practices, and follow-up studies will need to identify the specific mechanism of language interpreting related to cognitive control.

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