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Symmetries of comprehension-based language switch costs in conflicting versus non-conflicting contexts

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Abstract
Aims: The present study aimed to investigate the effect of contexts (i.e., non-conflicting context versus conflicting context) on bilingual language switch costs during language comprehension.
Methodology: Thirty-two unbalance Chinese-English bilinguals completed a modified comprehension-based language-switching task in two contexts. They made a judgement about the colour meaning of the word. In the non-conflicting context all words were presented in white ink, while in the conflicting context the words were printed in an inconsistent ink colour.
Data and analysis: Reaction time and accuracy data were analysed using mixed-effects models.
Findings/conclusions: Results showed that the switch costs were larger in the conflicting context than in the non-conflicting context. Further, in the non-conflicting context an asymmetrical switch cost with larger costs for the second language was observed as compared to symmetrical switch costs in the conflicting context.
Originality: This is the first study that indicates that bilingual comprehension-based language control adapts flexibly depending on the context, just as during bilingual production.
Significance/implications: These findings supported and expanded the classic adaptive control hypothesis.

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Keywords
Switch costs, language switching, conflicting context, language comprehension

Introduction

According to the adaptive control hypothesis, language control, which is a cognitive mechanism allowing bilinguals to speak in the intended language without intrusion from the nontarget language, can be modulated by processing contexts (Declerck & Philipp, 2015; Liu et al., 2018; Timmer, Christoffels, & Costa, 2018; for a review, see Green & Abutalebi, 2013). For example, Liu et al. (2018) asked non-proficient Chinese-English bilinguals to name the printed colour of the words while switching between their first (L1) and second languages (L2) in a non-conflicting context (non-colour words were presented in red, green or blue) or in a conflicting context (colour words were presented in an inconsistent colour). The language switch costs and the language asymmetry of the costs (L1 versus L2) were larger in the conflicting context compared to the non-conflicting context, indicating that bilingual language control flexibly changes depending on the amount of conflict within the context. Whereas there is evidence for the context effects during bilingual language production, there is little evidence for such effects during bilingual language comprehension. Therefore, in the current study we set out to investigate whether comprehension-based language control can be modulated by processing contexts with different amounts of conflict.

To investigate comprehension-based language-switching processes, the language-switching task, with visually presented words, is often combined with a semantic categorization task (Macizo, Bajo, & Paolieri, 2012), a lexical decision task (Aparicio & Lavaur, 2014; Mosca & de Bot, 2017; Orfanidou & Sumner, 2005; Thomas & Allport, 2000), a number categorization task (Hirsch, Declerck, & Koch, 2015; Jackson, Swainson, Mullin, Cunnington, & Jackson, 2004), a picture–sentence matching task (Philipp & Huestegge, 2015) or a self-paced reading task (Bultena, Dijkstra, & Van Hell, 2014). It is typically found that switching from one language to another (switch trial) yields longer reaction times than repeating the same language in two subsequent trials (repetition trial), an effect typically referred to as the switch cost (e.g., Orfanidou & Sumner, 2005; Thomas & Allport, 2000; but see Bultena et al., 2014; Jackson et al., 2004; Mosca & de Bot, 2017; Philipp & Huestegge, 2015).

While comprehension studies typically demonstrate a switch cost, the patterns of these costs (L1 versus L2) are inconsistent in the current literature. Some studies showed asymmetrical switch costs (i.e., larger for the weaker L2 than for the stronger L1, or vice versa) (e.g., Aparicio & Lavaur, 2014; Jackson et al., 2004; Mosca & de Bot, 2017), whereas others demonstrated symmetrical switch costs (i.e., similar costs for L1 and L2) (e.g., Hirsch et al., 2015; Macizo et al., 2012). For example, a switch cost towards the L2 but not the L1 was found in a lexical decision task, in which unbalanced French-English bilinguals were instructed to decide if the presented letter string was a word (L1 or L2) or a nonword (Aparicio & Lavaur, 2014). By contrast, other studies showed similar language costs towards both languages (i.e., symmetrical). For example, in Experiments 3 of Macizo and colleagues' (2012) study, unbalanced Spanish-English bilinguals were asked to decide whether visually presented words (either in the LI or L2) referred to an animate or inanimate entity. The debate regarding the pattern of switch costs is ongoing, but the inconsistent results could potentially be due to the fact that the existing studies were conducted with different task contexts and involve different amounts or types of interference, which in turn may lead to different pattern of language switch costs.

Different language contexts have shown to influence bilingual language control processes within the language production literature (Olson, 2016; Timmer et al., 2018; Timmer, Grundy, & Bialystok, 2017). This is based on the adaptive control hypothesis, which proposes that the language(s) spoken within people's environment places different demands on the cognitive system and therefore alters the corresponding control abilities (Green & Abutalebi, 2013; also see Green & Wei, 2014). Specifically, when bilinguals speak their two languages in separate contexts (i.e., at home and at work) they are in a single-language context, but when they use both their languages in the same context the language control demands change and influence the functioning of the language control system (Hartanto & Yang, 2016). Not only the language context, but also the domain-general context has been shown to affect production-based language control (e.g., Liu et al., 2018). Liu et al. (2018) found larger switch costs when additional conflict was added, by means of adding a Stroop colour conflict, during language production. While context has been shown to influence language control in language production, it is currently unknown whether comprehension-based language control could also be influenced by such processing context. Therefore, we aim to provide the first directly tested evidence regarding whether context could affect comprehension-based language control.

To investigate the extent to which the processing contexts with different amounts of conflict affect the size of comprehension-based switch costs in bilinguals, we had unbalanced Chinese–English bilinguals perform a modified language-switching task in which the meaning of the colour words was categorized into warm or cold colours. In the non-conflicting context all colour words were presented in white ink, while in the conflicting context the colour words were presented in an incongruent ink colour. This manipulation is based on the 'reverse' Stroop effect (Blais & Besner, 2007; Durgin, 2000). The 'reverse' Stroop effect refers to slowed reaction times when indicating what the meaning of a colour word is under a conflicting ink colour condition other than a neutral ink colour condition. For example, when indicating which of four colour patches at the corners of the display is consistent with the meaning of the colour word, slower performance was found when colour words were presented in incongruent physical colour than when they were presented in medium grey (Durgin, 2000). Durgin (2000) argued that because visual processing is faster than verbal processing, the conflicting visual information (i.e., incongruent physical colour) is strongly disruptive of responding to verbal information, resulting in the 'reverse' Stroop effect. In the present study, the conflicting context also contains a 'reverse' Stroop effect compared with the non-conflicting context, leading to greater interference/conflict (mismatching word and ink colour) than in the non-conflicting context. Mismatching ink colour is a form of domain-general cognitive control (i.e., the 'reverse' Stroop effect). Domain-general control has, to some extent, been suggested to share overlapping inhibitory mechanisms with language control (Declerck, Grainger, Koch, & Philipp, 2017; Timmer, Calabria, & Costa, 2019; Timmer et al., 2017). Therefore, the need to resolve the 'reverse' Stroop effect-related interference might result in less inhibitory control available to deploy during language switching in the conflicting context. Therefore, we predict that the switch costs will be greater in the conflicting context than in the non-conflicting context.

Furthermore, we aimed to examine whether the (a)symmetrical pattern of comprehension-based switch costs could be shaped by processing contexts with different amounts of conflict. While the adaptive control hypothesis suggests that context adaptively modulates the workings of the bilingual language control network, it does not make clear predictions regarding the (a)symmetric patterns of switch costs. This is where the Bilingual Interactive Activation plus (BIA+) model, a model for understanding the process of bilingual language comprehension, comes in. The BIA+ model provides more specific suggestions regarding how comprehension-based language control could potentially adapt within the present study (Dijkstra & van Heuven, 2002). The BIA+ model consists of two subsystems: the word identification subsystem and the task/decision subsystem. During word identification, the visual input activates the sublexical/lexical orthographic and phonological representations. In return, these activate the semantic concept(s) and language nodes that indicate membership to a particular language. All of this information is then used in the task/decision subsystem to respond. Words from both languages are represented together in one single

Table 1. Means (and SDs) of the age of acquisition (AoA) and language proficiency self-ratings in four language skills for both Chinese and English.

Self-ratings	L1 (Chinese)	L2 (English)
AoA		8.72(2.02)
Listening[a]	6.16(0.86)	3.61(0.99)
Speaking[a]	5.87(0.88)	3.35(0.88)
Reading[a]	5.90(0.94)	4.23(1.02)
Writing[a]	5.29(1.19)	3.65(0.99)

[a]Self-rated proficiency score from 1 (lowest) to 7 (highest).
L1: first language; L2: second language.

lexicon, which means that they can also mutually inhibit each other. As L1 lexical representations have a higher resting level activation than L2 representations for unbalanced bilinguals, L1 words interfere more when switching into the L2 than vice versa (i.e., the language node of the stronger language inhibits words of the weaker language to a greater extent than vice versa). Therefore, in the non-conflicting context, we expect to find a larger switch cost for the L2 than for the L1.

But what about the effect of additional conflict caused by the ink colour in the conflicting context? We believe that the effect of ink colour might take place at the semantic level, as the ink colour refers to the concept of the meaning of the word. The link between a concept and the L1 is stronger than between the concept and the L2 for unbalanced bilinguals (Kroll & Stewart, 1994), as tested in the current study. Therefore, we expect that the semantic interference in the conflicting context will affect the L1 to a greater degree than the L2. Moreover, according to the BIA+ model (Dijkstra & van Heuven, 2002), the semantic interference would slow the L1 word recognition during the word identification system and increases the L1 switch cost, while the L2 switch cost stays similar to the cost in the non-conflicting context. Hence, we predict a symmetrical switch cost would be observed in the conflicting context.

Method

Participants

Thirty-two Chinese–English bilinguals, recruited from South China Normal University, participated in the experiment. All participants were right-handed with normal or corrected-to-normal vision. They all signed a written informed consent form before participating. They also completed a self-rating questionnaire about their language background and proficiency. The mean age of acquisition (AoA) was 8.72 (±2.02) years for English. The averages for their self-rated proficiency skills are presented in Table 1. Paired-sample *t*-tests revealed a statistically significant difference between the proficiency ratings in the L1 and L2 for all four language skills (all ts > 7.02, all ps < 0.001), suggesting that the participants were unbalanced bilinguals with lower L2 proficiency (see Table 1).

Task and procedure

A modified comprehension-based language-switching task combined with semantic categorization was conducted in the current study. The experimental materials were four English colour words ('red', 'yellow', 'green' and 'blue') and their Chinese translations. During the experiment, each trial began with a fixation cross ('+') presented for 500 ms, followed by a printed word. Participants

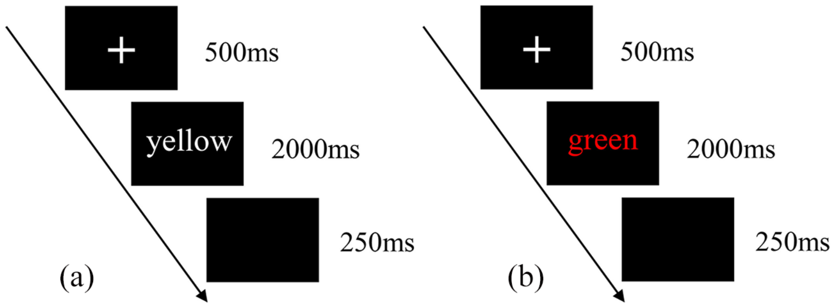

Figure 1. An example of the trial procedure in the non-conflicting (a) and the conflicting (b) contexts. It is noted that both contexts contain Chinese words and English words, which were presented in randomized order.

were instructed to decide whether the meaning of the printed word belongs to a warm or cold colour. They responded with the left or right index finger on the 'F' or 'J' key of a keyboard, which were counterbalanced across participants. The printed word remained on the screen until a response was given or after 2000 ms had passed. The next trial began after the presentation of a blank screen for 250 ms (see Figure 1).

The task was performed in a non-conflicting and in a conflicting block. In the non-conflicting block, colour words were all presented in white ink (e.g., the word 'green' was presented in white) instead of in the congruent colour, aiming to avoid potential facilitation of the ink colour or decision making purely based on the ink colour. In the conflicting block, colour words were presented in an inconsistent colour with the word meaning (e.g., the word 'blue' was presented either in red, yellow or green), with word order and ink colour order randomized. Hence, the colour words and ink colour could repeat or switch between consecutive trials. The order of blocks was counterbalanced across participants. The experiment conforms to a 2 (contexts: non-conflicting versus conflicting) × 2 (language: L1 versus L2) × 2 (transition: repetition versus switch) within-subject design, with reaction time (RT) and accuracy (ACC) as the dependent variables. The ratio of repeat and switch trials was 1:1 for each language in both blocks. There were 61 experimental trials in each block, with the first trial being the filler trial, so there are 15 trials for each trial type (i.e., L1 repeat, L2 repeat, L2–L1 switch and L1–L2 switch). Before the experimental blocks, there was a practice block of 10 trials.

Results

The error trials, as well as the trials following an error were excluded from RT analyses. The first trial of each block was also excluded. Outliers, RTs larger or smaller than 2.5 SDs from the mean (per condition, such as L2–L1 switch trials in the conflicting context) were also removed from further analyses (Wang, Fan, Liu, & Cai, 2016). These criteria led to the exclusion of 8.2% of the data (ranging from 3.3% to 10.0% for different conditions). In addition, we discarded one participant because of an error rate higher than 20% (Heikoop, Declerck, Los, & Koch, 2016) (see Table 2).

Mixed-effects models were conducted on the data, running with the lme4 package (Bates, Sarkar, Bates, & Matrix, 2007) and the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2014) in the statistical software R (version 3.4.3). Mixed-effects models are preferable to an analysis of variance (ANOVA) because they allow random effects of participants and items to be considered simultaneously, making the data modelling more appropriate and the results generalizable to the other

Table 2. Mean reaction times (RTs) and accuracy (ACC) for non-conflicting and conflicting contexts (standard deviations in parentheses).

	Non-conflicting		Conflicting	
	L1 (Chinese)	L2 (English)	L1 (Chinese)	L2 (English)
RT				
Repetition	555(48)	553(54)	578(64)	599(71)
Switch	558(58)	577(55)	613(70)	631(73)
Switch costs	3(25)	24(27)	35(29)	32(34)
ACC				
Repetition	.94(.07)	.96(.04)	.92(.13)	.93(.12)
Switch	.96(.05)	.96(.04)	.93(.12)	.93(.13)
Switch costs	.02(.07)	.00(.04)	.01(.06)	.00(.06)

L1: first language; L2: second language.

Table 3. Mixed-effects model for reaction times.

Fixed effects	Estimate	*SE*	*t*-value
Intercept	583.30	10.13	57.61***
Contexts	45.16	13.62	3.32**
Transition	24.16	3.11	7.76***
Language	14.18	8.73	1.63
Contexts × Transition	19.96	5.76	3.47***
Contexts × Language	10.14	17.25	0.59
Transition × Language	6.03	5.76	1.05
Contexts × Transition × Language	–34.02	11.51	–2.96**

*p < .05; **p < .01; ***p < .001.

subjects and items. We fit a linear mixed-effect model for RT data with contexts (non-conflicting versus conflicting), language (L1 versus L2), transition (repetition versus switch) and their interactions as fixed effects. As random effects, we included by-participant and by-item random intercepts, by-participant random slopes for contexts, language and transition, and by-item random slopes for contexts. The other factors and the interactions among the three within-subject factors were consequently excluded in the fitted model because they did not improve the model fit (ps > .05) (see Hsu & Novick, 2016). For this model, all the variables were coded using mean-centred contrast coding (i.e., non-conflicting = −0.5, conflicting = 0.5; repetition = −0.5, switch = 0.5; L1 = −0.5, L2 = 0.5), yielding tests of the main effects directly analogous to that obtained from an ANOVA.

As can be seen in Table 3, the RT data revealed a significant main effect of contexts (t = 3.32, p = 0.002), with reaction time in non-conflicting (561 ms) being faster than in conflicting contexts (605 ms), as was the significant main effect of transition (t = 7.76, p < 0.001), with switch trials (595 ms) being slower than repetition trials (446 ms). The interaction between contexts and transition was also significant (t = 3.47, p < 0.001), with smaller switch costs in the non-conflicting context (14 ms) than in the conflicting context (34 ms). To further understand this interaction, we conducted separate submodels for the non-conflicting context and the conflicting context (see online Supplemental Tables S1 and S2). In the non-conflicting context, we found a non-significant main effect of transition (t = 1.65, p = 0.142), indicating a non-significant switch cost. In contrast,

Table 4. Mixed-effects model for accuracy.

Fixed effects	Estimate	*SE*	*z*-value
Intercept	3.47	0.22	15.96***
Contexts	0.04	0.29	0.14
Transition	0.03	0.15	0.20
Language	0.03	0.23	0.15
Contexts × Transition	–0.14	0.23	–0.63
Contexts × Language	–0.03	0.42	–0.08
Transition × Language	–0.38	0.22	–1.70
Contexts × Transition × Language	0.21	0.45	0.49

*$p < .05$; **$p < .01$; ***$p < .001$.

we found a significant main effect of transition in the conflicting context ($t = 3.56$, $p = 0.002$), indicating a significant switch cost. In addition, the three-way interaction with language included was also significant ($t = -2.96$, $p = 0.003$), showing a modulation of the asymmetrical switch costs by processing contexts. Further submodelling analyses showed larger L2 switch costs (24 ms) than L1 switch costs (3 ms, although there were no significant switch costs here) in the non-conflicting context (i.e., asymmetrical switch costs) ($t = 3.31$, $p < 0.001$), while there was no difference between L1 switch costs (35 ms) and L2 switch costs (32 ms) in the conflicting context (i.e., symmetrical switch costs) ($t = -1.15$, $p = 0.249$) (see online Supplemental Tables S3 and S4).

Similarly, the logistic mixed-effects model was fitted to accuracy data, with the same fixed structure and random effects as in the linear mixed-effects model for RT. However, none of the main effects or interaction effects were statistically significant (see Table 4).

Discussion

The present study examined whether the comprehension-based language switch costs in bilinguals would be influenced by processing contexts with different amounts of conflict. The task required unbalanced Chinese–English bilinguals to perform a comprehension language-switching task in a conflicting and a non-conflicting context. The results showed larger switch costs in the conflicting context than in the non-conflicting context. Meanwhile, asymmetrical switch costs were observed with larger costs for the L2 in the non-conflicting context, and symmetrical switch costs were observed in the conflicting context. This demonstrates that the size of the switch costs and the (a) symmetrical pattern of switch costs flexibly changes depending on the processing context.

While previous studies have shown that production-based language control could be modulated by the processing context with different amounts of conflict (e.g., Liu et al., 2018), whether the comprehension-based language control could also be modulated by the processing context remains unclear. Based on the BIA+ model and the adaptive control hypothesis, the present study examined the impact of the processing contexts with different amounts of conflict on comprehension-based language switch costs by using a ‘reverse’ Stroop effect (Durgin, 2000) to create conflict during a semantic categorization task.

The current study showed that the switch costs during language comprehension were larger in the conflicting than in the non-conflicting context. This context effect is very similar to the observed ‘reverse’ Stroop effect in previous studies (e.g., Durgin, 2000); participants were required to respond to the meaning of the colour word, while an incongruent ink colour (i.e., incongruent trials) or medium grey (i.e., neutral trials) is imposed on the word. Longer reaction times and higher error rates were found for incongruent than for neutral trials (i.e., ‘reverse’ Stroop interference effect). Durgin (2000) suggested that, because visual processing is faster than verbal processing, the conflicting visual information (i.e., incongruent ink colour) is strongly disruptive of responding to verbal information, leading to the ‘reverse’ Stroop effect. Similarly, in the current study, the larger switch cost in the conflicting context might arise from the unmatched conflicting visual colour information. In other words, in the conflicting context, inhibitory control had to be deployed to solve the ‘reverse’ Stroop effect-related interference, and therefore there is less inhibitory control available to deploy during language switching, resulting in larger switch costs in the conflicting context than in the non-conflicting context. The information theory could account for our results (Cooper, Garrett, Rennie, & Karayanidis, 2015; Fan, 2014). The conflicting context contains more information entropy or uncertainty (i.e., additional ‘reverse’ Stroop effect) than the non-conflicting context, which results in a greater need for information processing and in turn a larger switch cost in the conflicting context. This is also in line with the conflict monitor hypothesis, which postulated that a ‘conflict monitoring’ system exists that monitors for the occurrence of conflicts in contextual information processing (Botvinick, Braver, Branch, Carter, & Cohen, 2001). Compared to the non-conflicting context with only language switching, the conflicting context with both language switching and the ‘reverse’ Stroop effect produces more conflict, resulting in larger switch costs.

The current result can also be accounted for by the BIA+ model (Dijkstra & van Heuven, 2002). Compared to the non-conflicting context, the additional semantic interference (i.e., incongruent ink colour) in the conflicting context could create a slowdown at the semantic nodes within the identification system that feeds back to the language nodes, eventually leading to a larger switch cost. Previous studies with interlingual homophones (i.e., words having the same pronunciation but different meanings in two languages) have shown a slowdown in reaction times as compared to control words (i.e., the same meaning in two languages). Interlingual homophones have interference at the semantic level, leading to a slowdown due to conflicting concepts (Schulpen, Dijkstra, Schriefers, & Hasper, 2003). In the present study, the slowdown occurs at the semantic level due to the conflicting ink colour concept.

More interesting are the different (a)symmetrical patterns of language switch costs in the conflicting context as compared to the non-conflicting context. In the non-conflicting context, we find an asymmetrical switch cost, with a larger cost for the L2 than the L1. More precisely, there was a significant switch cost to the L2 but not to the L1. This result replicates Aparicio and Lavaur’s (2014) study, where unbalanced French-English bilinguals showed language-switching costs only in the L2 but not in the L1 while performing a lexical decision task to decide whether the presented letter string (either L1 and L2) was a word or not. This observation is consistent with BIA+ model (Dijkstra & van Heuven, 2002), which suggests L1 words have a higher resting level of activation than L2 words for unbalanced bilinguals. Therefore, in a switch trial interference from the L1 into the L2 is greater than vice versa, leading to larger costs to the weaker L2 than for the stronger L1.

In contrast to the asymmetrical cost in the non-conflicting condition, symmetrical switch costs were observed in the conflicting context. How can language control models accommodate this observation? The most likely explanation is that access to lexical representation of the two languages is altered to a different degree by the additional semantic interference in the conflicting context as compared to the non-conflicting context. The BIA+ model suggested that L1 words have a higher resting level of activation than L2 words, meaning they are processed more rapidly. Processing of ink colour is faster than verbal processing (Durgin, 2000), and therefore it can be more disruptive for processing faster L1 than slower L2 words. Moreover, the Revised Hierarchical Model suggests that connections between the L1 lexicon and the conceptual system were stronger than those between the L2 lexicon and the conceptual system (Kroll & Stewart, 1994). Hence, the conflicting colour at the semantic (conceptual) level in the conflicting context would have more interference for the L1 switch cost. Thus, the additional conflict increased the L1 switch cost from

3 ms in the non-conflicting context to 35 ms in the conflicting context, while it stayed the same for the L2 (respectively, from 24 to 32 ms).

As described earlier, we found switch costs for switches into the L2, but not for switches into the L1 (i.e., asymmetrical switch costs), in the non-conflicting context. This result is different from previous findings on bilingual semantic categorization, which showed the same amount of switching costs in both the L1 and L2 (i.e., symmetrical switch costs, see Macizo et al., 2012). The main difference between the present study and previous studies lies in the number and type of stimuli used. While the present study included only four colour words with different colours, previous studies, such as Macizo et al. (2012), entailed a set of 144 words in 12 categories. These differences induce different processing contexts with different degrees of interference. In Macizo et al.'s (2012) study, the increased number of words and categories leads to more interference (conflict), possibly similar to the conflicting context with more interference in current study, and both of them found a symmetrical switch cost.

Our findings support and expand the adaptive control hypothesis (Green & Abutalebi, 2013), which suggests context modulates language control. The adaptive control hypothesis postulates that control processes adapt to the demands of the interactional contexts of language use placed upon them. However, the evidence supporting this hypothesis was mainly limited to language production studies so far (e.g., Liu et al., 2018). The present study shows that processing contexts (i.e., non-conflicting context or conflicting context) also affect control processes within language comprehension. Therefore, it can be concluded that processing context could modulate language control in both language production and language comprehension.

To conclude, the current study suggests a critical role of processing contexts on the control patterns within comprehension-based language switching. In other words, (a)symmetries can change depending on the degree of interference within a task.

Conclusion

In summary, the present study revealed different sizes and (a)symmetrical patterns of comprehension-based language switch costs in conflicting versus non-conflicting contexts. This led to the conclusion that processing contexts with different amounts of conflict play a critical role in modulating the bilingual language switch costs during comprehension.

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Supplemental material

Supplemental material for this article is available online.

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