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SPECIAL ISSUE ARTICLE

# Post-conflict slowing effects in monolingual and bilingual children

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## Abstract

*Previous research has shown that bilingual children outperform their monolingual peers on a wide variety of tasks measuring executive functions (EF). However, recent failures to replicate this finding have cast doubt on the idea that the bilingual experience leads to domain-general cognitive benefits. The present study explored the role of disengagement of attention as an explanation for why some studies fail to produce this result. Eighty children (40 monolingual, 40 bilingual) who were 7 years old performed a task-switching experiment. In the pure blocks, three simple non-conflict tasks were performed in which children responded by pressing one of two response keys. In the conflict block, occasional bivalent stimuli appeared and created conflict because the irrelevant dimension was mapped to the incorrect response key. The results showed that these bivalent stimuli affected subsequent performance in the conflict block. For monolinguals, the effect of conflict was found for up to 12 trials after the appearance of the bivalent stimulus, but for bilinguals the effect disappeared after only two trials. The results are interpreted as evidence for faster disengagement of attention by bilingual children. Most studies examining EF in monolingual and bilingual children do not examine trial-by-trial adjustments following conflict, but these are essential considerations because relevant processing differences are masked when analyses are applied to data averaged across entire blocks.*

## Research highlights

- There are conflicting results in the literature regarding whether or not monolingual and bilingual children perform differently on executive function tasks.
- The present study examined the effect of conflict on subsequent trial-by-trial adjustments.
- Standard analyses comparing overall reaction times showed no differences between language groups.
- More detailed analyses revealed shorter-lived post-conflict slowing for bilingual than monolingual children following the appearance of a stimulus that creates response conflict.
- Evidence supports the interpretation that bilinguals are better able to rapidly disengage attention and refocus on current demands.

## Introduction

Children must adapt to their constantly changing environments in order to physically and cognitively navigate through their world, avoiding distraction from irrelevant or conflicting information. For bilingual children, environmental conflict is pervasive because it includes competition from two jointly activated languages that compete for selection (Martin, Dering, Thomas & Thierry, 2009; Spivey and Marian, 1999; Timmer, Ganushchak, Ceusters & Schiller, 2014; Thierry & Wu, 2007; Wu & Thierry, 2010, 2012; for review see Kroll, Dussiss, Bogulski & Valdes-Kroff, 2012). The premise in research on bilingualism is that both general adaptation to conflict and language selection are handled by similar domain-general processes that are part of the executive function (EF) system (Bialystok, Craik, Green & Gollan, 2009). The constant use of these processes for language selection strengthens them, making them more efficient for other tasks, including nonverbal ones. Consistent with this view, many studies have shown that bilingual children outperform monolingual children on nonverbal tests of EF (meta-analysis in Adesope, Lavin, Thompson & Ungerleider, 2010; review in Barac, Bialystok, Castro & Sanchez, 2014).

In spite of a substantial amount of evidence supporting the relation between bilingualism and EF performance in

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children, there are some studies that have not found these effects, instead reporting no difference between the groups (Duñabeitia, Hernández, Antón, Macizo, Estévez *et al.*, 2015; Gathercole, Thomas, Kennedy, Prys, Young *et al.*, 2014). Resolution of the discrepant results requires a more precise description of the mechanism by which these effects take place, yet the specifications for such a mechanism constitute a significant gap in the literature. The present study addresses this issue by investigating the role of a potential source of difference between EF processing in monolingual and bilingual children, namely, the ability to rapidly disengage attention in a complex changing environment.

The possibility that there are EF differences between monolingual and bilingual children is important because of the role that EF plays in development. Better scores on EF measures predict increased academic success over time in both math (Best, Miller & Naglieri, 2011; Clark, Pritchard & Woodward, 2010) and reading (Best *et al.*, 2011) and are associated with long-term outcomes for achievement and health (Duncan, Ziol-Guest & Kalil, 2010). Establishing the validity of the role of bilingualism in promoting EF, therefore, has important consequences. The problem is that EF is an umbrella term, and descriptions of its structure vary. However, central to all notions of EF is some form of attention, planning, and goal-directed behavior (Banich, 2009). The current approach focuses on the role of attention.

Following from influential models of EF (Miyake, Friedman, Emerson, Witzki, Howerter *et al.*, 2000) and bilingual language processing (Green, 1998) at the time these explanations were being proposed (Bialystok *et al.*, 2009), a crucial element of both domain-general control and language selection appeared to be inhibition. Specifically, inhibition was necessary to avoid interference from misleading environmental cues (e.g. inhibit name of word on Stroop task to focus on color of ink) and also to avoid interference from the jointly activated word in the non-target language (e.g. inhibit ‘chien’ to select ‘dog’). The early proposal, therefore, was that the experience of language management improved bilingual ability with inhibitory control.

Early evidence from children (Bialystok, Barac, Blaye & Poulin-Dubois, 2010; Martin-Rhee & Bialystok, 2008; Yang, Yang & Lust, 2011; Yoshida, Tran, Benitez & Kuwabara, 2011) and toddlers performing EF tasks (Crivello, Kuzyk, Rodrigues, Friend, Zesiger *et al.*, 2016; Kuipers & Thierry, 2015; Poulin-Dubois, Blaye, Coutya & Bialystok, 2011) supported this idea. For example, Martin-Rhee and Bialystok (2008) had monolingual and bilingual children perform a Simon task, in which children must respond to the color of a stimulus while ignoring the location of the stimulus. On some trials, the button for the relevant color and the location of the stimulus appeared on the same side (e.g. left button press, stimulus on the left side of the screen) and on other trials the location and the button press did not appear on the same side, creating conflict. Bilingual children were faster than monolingual children on this task, and the authors concluded that bilingual children were better able than monolingual children to inhibit attention to irrelevant cues. A similar pattern was observed in 2-year-old toddlers, such that bilingual toddlers performed better than monolingual toddlers on a variant of a Stroop task (Poulin-Dubois *et al.*, 2011). However, there are problems with these explanations in terms of inhibition. The aforementioned studies and others have shown that bilingual children perform better than monolingual children not only on conflict trials where inhibition might be necessary (i.e. incongruent trials) but also on other trials and tasks where inhibition is not necessary (i.e. congruent trials; Kapa & Colombo, 2013; Yang *et al.*, 2011).

Further evidence that makes it unlikely that inhibition of jointly activated language representations is the primary mechanism for the enhancement of EF in bilingual children comes from studies with infants. Using eye-tracking, Kovács and Mehler (2009) recorded eye gazes of 7-month-old infants during a reward anticipation task. A cue was presented in the center of the screen followed by a reward (i.e. a puppet) on one of two sides of the screen. The manipulation was that the reward appeared consistently on one side of the screen during the first half of the experiment and then switched to the other side of the screen. All infants learned to anticipate the reward on the correct side of the screen during the first half of the experiment. However, only bilingual infants learned to redirect attention to the new location during the second half of the experiment; monolingual children continued to anticipate reward on the same side as it was initially learned. These results demonstrate that prior to language mastery, bilingual infants display enhanced attentional control and the ability to override a learned response with a new one. A more recent study showed that bilingual infants learn at an earlier age than monolingual infants to focus attention on the mouth more than the eyes in order to detect speech from talking faces, a strategy that is found in more mature performance (Pons, Bosch & Lewkowicz, 2015). Therefore, rather than inhibition, the relevant process appears to be some aspect of selective attention. Whether or not the irrelevant cue is inhibited (the word in the Stroop task, the non-target language in language selection, or the previously relevant position in the infant studies), the correct response requires actively attending to the relevant cue in the context of distraction. It is this selection that appears to be more developed in bilingual children.

The proposal investigated in the present study is that differences in this selective attention can be defined in terms of the ability to rapidly disengage attention from previous targets, freeing the system to focus on the currently relevant cue. If attention perseverates on previously relevant or salient information, then performance is disrupted when there is a change in the relevant cue. In these terms, switching attention away from the salient color word in the Stroop task, from the irrelevant flankers in the flanker task, or from the previously rewarded position in the infant task requires disengagement so that attention can be deployed on the current trial. The present study suggests that this is what bilingual children do better. This idea endorses a new theoretical perspective for how cognition changes as a result of the bilingual experience.

This view based on selective attention and disengagement of attention is different from the inhibition explanation in several important ways. First, inhibition of irrelevant information occurs on the current trial and can explain why performance may differ on conflict trials but cannot account for performance on non-conflict trials. Disengagement, in contrast, describes a process that occurs *after* conflict and can explain why performance differs on both subsequent conflict and non-conflict trials. Thus, the scope of the explanation extends beyond the current trial. Similarly, tasks that do not explicitly require inhibition, such as multitasking in dual task paradigms, are also performed better by bilingual children, even though no inhibition appears to be involved (Bialystok, 2011). Finally, theoretical interpretations for inhibitory accounts often focus on how these processes are enhanced when the irrelevant language is inhibited, but such accounts fail to explain differences between preverbal infants being raised in different language environments (e.g. Pons *et al*., 2015; Singh, Fu, Rahman, Hameed, Sanmugam *et al*., 2015). Thus, it is likely that even before language is acquired, development of general attentional processes is enhanced through the experience of being in a more complex linguistic environment and it is these attentional processes that contribute to performance differences between monolinguals and bilinguals. Even in the first year of life, bilingual infants can distinguish between two languages by visual cues alone, but monolingual infants cannot (Sebastián-Gallés, Albareda-Castellot, Weikum & Werker, 2012; Weikum, Vouloumanos, Navarra, Soto-Faraco, Sebastián-Gallés *et al*., 2007). Therefore, it is beneficial for bilingual infants to be able to quickly shift attention between these languages in order to optimize learning in the continually changing environment.

The present study used a paradigm that assesses the influence of previous trial conflict on subsequent performance. The paradigm compares reaction times (RT) to simple univalent stimuli in two contexts, one in which there are no additional distractions (purely univalent) and one in which these simple univalent stimuli follow conflict (bivalent stimulus). To the extent that the conflict from the bivalent stimulus continues to influence performance, responses to the subsequently presented univalent stimuli will be impacted. A reaction time cost for univalent stimuli following bivalent stimuli compared to univalent stimuli in pure blocks is observed. Rapidly disengaging attention from the bivalent stimulus reduces the long-lasting effect of this RT cost.

The cost attributable to the previously conflicting stimulus is called the *bivalency effect* (Grundy, Benarroch, Woodward, Metzak, Whitman *et al*., 2013, Grundy & Shedden, 2014a, 2014b; Meier, Woodward, Rey-Mermet & Graf, 2009; Woodward, Meier, Tipper & Graf, 2003). In this paradigm (see Figure 1), participants typically switch between three simple univalent tasks: a parity decision (odd vs. even numbers), a case decision (uppercase vs. lowercase letters), and a color decision (red vs. blue shapes). In univalent blocks, only one of these dimensions is relevant, but in conflict blocks, occasional bivalent stimuli appear in the form of colored letters. The color is irrelevant to the judgment of letter case, but because it is associated with a response, it creates conflict. The trials are usually constructed so that the response associated with the irrelevant color is different from the response required for the letter stimulus, creating response conflict. The bivalency effect is measured as the difference between the reaction times to univalent trials following bivalent stimuli and the reaction times to univalent trials in purely univalent blocks. A post-conflict slowing effect is observed in which univalent trials that appear in a conflict block that includes occasional bivalent stimuli are responded to more slowly than univalent trials that appear in a block of purely univalent stimuli. Thus, the post-conflict slowing effect is similar to mixing costs in a typical task-switching paradigm (Los, 1996; Monsell, 2003; Rubin & Meiran, 2005), but different in that the critical slowing occurs on univalent trials rather than bivalent trials. They also differ from mixing costs in that they are calculated in terms of their exact position in a sequence of trials, not simply their presence in a switching condition. This paradigm allows for a purer measure of disengagement processes because it measures slowing on non-conflict trials that *follow* a conflict trial, rather than slowing that occurs on a conflict trial itself. Furthermore, because most trials are univalent within the conflict blocks, one can examine how long the bivalent

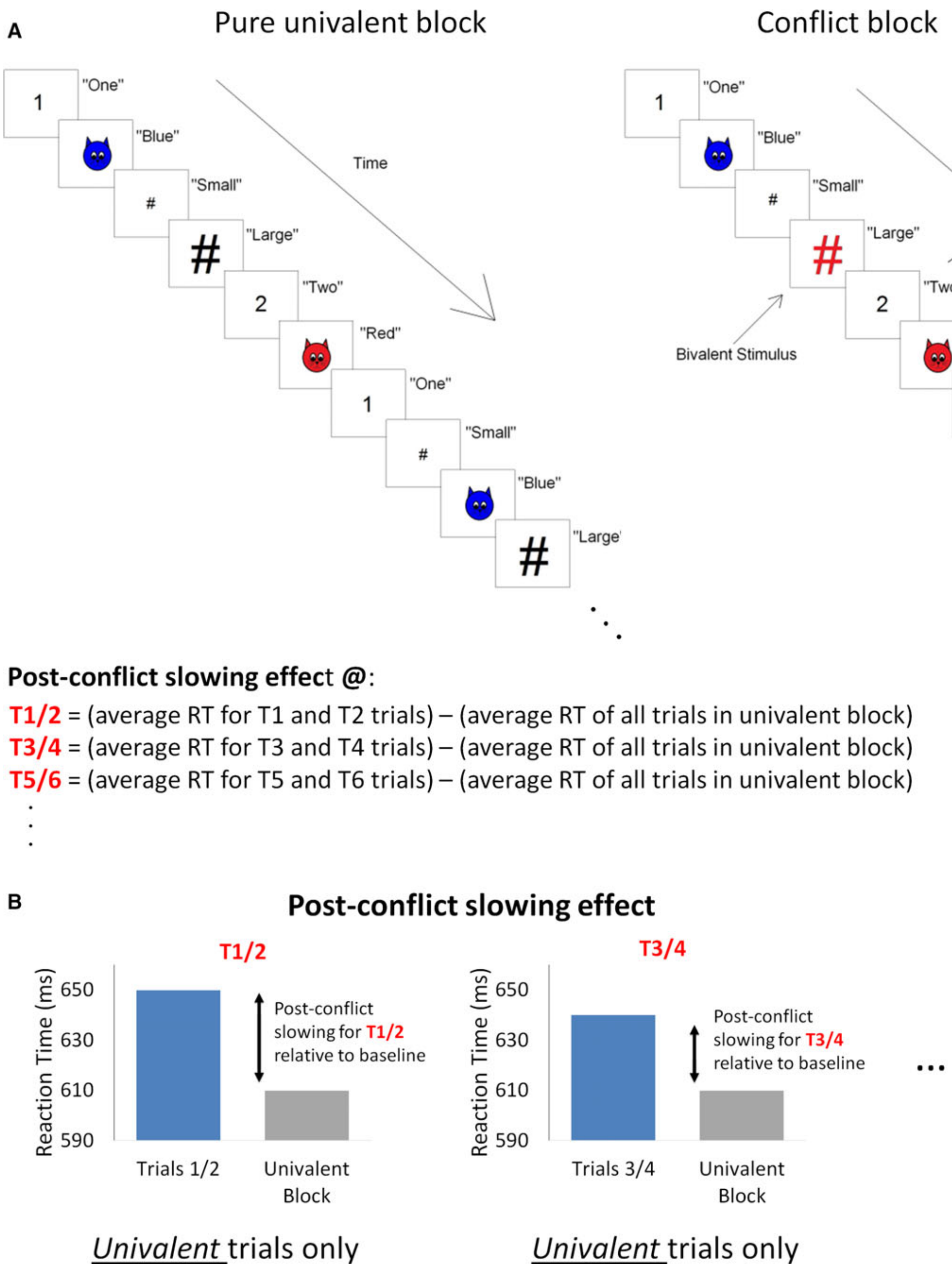


**Figure 1** *(A) The bivalency effect paradigm used in the present experiment to examine post-conflict slowing effects. (B) The trajectory of the post-conflict slowing effect is examined by looking at a number of trials following the bivalent stimulus and subtracting baseline performance of univalent trials in purely univalent blocks. T1/2 = first two trials following a bivalent stimulus, T3/4 = third and fourth trials following a bivalent stimulus, T5/6 = fifth and sixth trials following a bivalent stimulus.*

stimulus influences performance on subsequent univalent trials.

If disengagement processes are part of the explanation for better performance by bilinguals on executive function tasks, then it would help explain why sometimes no differences are found between monolingual and bilingual participants performing these tasks (Duñabeitia *et al*., 2015; Gathercole *et al*., 2014). Most of these studies use tasks that require switching between successive bivalent stimuli. It is well known that the congruency of the previous bivalent stimulus affects how an individual responds to the current bivalent stimulus (Botvinick, Braver, Barch, Varter & Cohen, 2001; Gratton, Coles & Donchin, 1992; Wang, Wang, Chen, Hitchman, Liu *et al.*, 2015; Weissman, Egner, Hawks & Link, 2015; review in Egner, 2014). Furthermore, this performance adaptation is affected by disengagement processes (Compton, Arnstein, Freedman, Dainer-Best & Liss, 2011; Compton, Huber, Levinson & Zheutlin, 2012). Rapid disengagement should benefit (i.e. faster RTs, fewer errors) performance when the following stimulus is switched, but hinder performance (i.e. slower RTs, more errors) when the following stimulus is repeated. If bilinguals and monolinguals differ in terms of their ability to rapidly disengage from previous trials, collapsing across previous trial information would mask important group differences. In other words, if the task requires switching over successive bivalent stimuli, positive and negative effects may cancel each other and group differences would be concealed. The bivalency effect paradigm is ideal for examining disengagement processes because one can look at performance following conflict to see how long the effects of conflict influence subsequent univalent trials.

In the present study, monolingual and bilingual children performed a child-friendly version of the bivalency effect paradigm. The hypothesis was that bilingual children will be less affected than monolingual children by the occasional appearance of a bivalent stimulus. Specifically, the prediction was that the post-conflict slowing effect caused by the unexpected bivalent stimulus would be shorter-lived for bilingual children than for the monolinguals because of more rapid disengagement.

## Method

### *Participants*

Eighty-eight children who were 7 years old were recruited from public schools in a large multicultural city. Participants whose overall accuracy across all trials of the bivalency task fell 2.5 standard deviations below the group mean of 88% were excluded from analysis. This resulted in the exclusion of eight outliers whose accuracy was less than 67%, three of whom were monolingual and five of whom were bilingual. Scores from these outliers were not significantly different from chance level because of failure to follow instructions, failure to understand instructions, or inability to sit still throughout testing, so results would not have been interpretable. The final sample consisted of 40 monolingual and 40 bilingual children.

### *Background measures*

Table 1 provides means for all background measures for each group. Children were identified as monolingual or bilingual based on proficiency in speaking and understanding English and their other language, as well a composite score representing practice of and exposure to a second language. These scores were obtained from the Language and Social Background Questionnaire (LSBQ; Luk & Bialystok, 2013) that parents filled out along with consent forms prior to the child's participation. Proficiency in speaking and understanding a second language were each measured on a 5-point scale ranging from 'Poor' to 'Excellent' and then given a numerical score out of 5. Practice and exposure scores were measured on a 7-point scale across six items, ranging from 'All English' to 'Only in the other language'. For example, two of the *usage* items are the following: 'Language child speaks to: Mother' and 'Language child speaks to: Father'. Examples of the *exposure* items are the following: 'Language spoken in the home to the child by: Mother' and 'Language spoken in the home to the child by: Father'. All items were given equal weight, then averaged and converted to a composite score out of 10. Socioeconomic status was assessed by maternal education. The Peabody Picture Vocabulary Task-III, Form A (PPVT-III) was administered as a test of English receptive vocabulary and Raven's colored progressive matrices test (Raven, Court & Raven, 1996) was used to assess nonverbal visuospatial reasoning. The PPVT and the Raven's tasks are valid and reliable measures of vocabulary size and non-verbal intelligence, respectively. Both measures were converted to standard scores out of 100 with a standard deviation of 15.

### *Bivalency effect task*

Figure 1 provides an example of trials that appeared in the bivalency effect paradigm. Children performed three

**Table 1** *Means (and standard deviations) for background measures*

| | Monolingual | Bilingual |
|---|---|---|
| *N* | 40 | 40 |
| Age (years) | 7.2 (0.38) | 7.4 (0.51) |
| Number of males | 22 | 24 |
| Mother's education (years) | 3.6 (0.82) | 3.7 (1.23) |
| Raven's matrices (standardized to 100) | 95.6 (14.6) | 92.4 (18.8) |
| PPVT (standardized to 100) | 103.3 (12.5) | 91.8 (14.9) |
| L2 proficiency (out of 5) | | |
| Speaking | 0.35 (0.70) | 2.38 (1.3) |
| Understanding | 0.45 (0.82) | 2.75 (1.08) |
| L2 practice/exposure (out of 10) | 0.22 (0.52) | 5.16 (2.6) |

binary-choice response tasks within three experimental blocks: one conflict block flanked by two purely univalent blocks. The univalent stimuli consisted of three types of judgment. For the color decision task, children were required to indicate whether a cat was red or blue; for the parity decision task, children indicated whether they saw a '1' or a '2'; and for the size decision task, children indicated whether the symbol '#' was large or small (the large symbol was approximately three times the size of the small symbol). All three univalent tasks were presented in random order in each of the three experimental blocks. In the conflict block, the presentation included an occasional bivalent stimulus that created response conflict. This stimulus was a red or blue colored symbol, and children were told to ignore the color and simply respond to whether the symbol was large or small. The response button associated with the irrelevant color was always incongruent to the response required to make a correct size decision.

A mouse was placed on each side of a laptop computer and served as a left or right response key. Children rested one hand on each of the mice, and each mouse was associated with one of the two binary responses. All stimuli were presented on a white background on a 17″ Dell Latitude (E6500) laptop monitor with a refresh rate set to 60 Hz. Stimuli subtended an average vertical visual angle of approximately 2.9° and horizontal visual angle of approximately 2.2°. Stimuli remained on the screen until the participant responded or until 3000 ms elapsed, after which an 800 ms inter-trial interval that displayed a fixation cross was shown before appearance of the next trial. Feedback displays during practice were presented for 1500 ms immediately following responses ('Good!☺' for correct, 'Oops!' for incorrect).

### *Procedure*

After obtaining informed consent from parents, children completed the PPVT and Raven's progressive matrices followed by the bivalency effect task in a single session that lasted approximately 30 minutes. In the bivalency effect task, children were given six practice trials for each of the three tasks individually to familiarize themselves with the stimuli. Following this was a practice block containing 24 univalent trials with feedback in which all three tasks were randomly presented. Feedback was given on all practice trials. The three experimental blocks followed (see Figure 1 for an example of each type of block). The first and third blocks were univalent and included stimuli from all three tasks in random order. The second block was the conflict block in which bivalent trials appeared randomly on one-third of symbol judgment trials. Each of the three blocks contained 72 trials (24 color judgment trials, 24 size judgment trials, 24 parity judgment trials).

### *Data analyses*

Accuracy and RT data were first analyzed by means of a Group (bilingual vs. monolingual) × Trial type (bivalent trials in conflict blocks, univalent trials in conflict blocks, univalent trials in univalent blocks) mixed-measures ANOVA.

Following this, an analysis was conducted to examine post-conflict effects. This analysis was based on univalent trials only. Trials following bivalent stimuli were grouped into bins of two trials each and the average RT for each bin was used to calculate post-conflict slowing. Thus, T1/2 indicates the average reaction time of the first and second trials following a bivalent stimulus, T3/4 the third and fourth trials following a bivalent stimulus, etc. Because bivalent stimuli appeared randomly on 8 out of the 72 trials in the conflict block, it was rare for any participants to see univalent trials that exceeded trial position 12 before another bivalent stimulus was encountered. Thus, trials that exceeded trial position 12 were not reliable and were excluded from analyses. Furthermore, previous work has shown that the bivalency effect is reliable up to 20 seconds following a bivalent stimulus (Meier *et al*., 2009); with an average RT of approximately 1000 ms in the present study (see Table 2) and an inter-trial-interval of 800 ms, 12 trials span approximately 20 seconds. Finally, analyses were conducted on pairs of trials rather than individual trials because 12 levels of a variable is not as reliable as 6, one reason being that there would not be enough trials per bin. Thus, the analysis was a Group (monolingual vs. bilingual) by Trial Position (Trials 1/2, Trials 3/4, Trials 5/6, Trials 7/8, Trials 9/10, Trials 11/12) mixed-measures ANOVA. The post-conflict slowing effect scores were calculated as the difference between RTs at each trial position bin

**Table 2** *Reaction times and proportion correct (and standard deviations) for bivalent and univalent trials*

| | Reaction times | | Proportion correct | |
|---|---|---|---|---|
| | Monolingual | Bilingual | Monolingual | Bilingual |
| Bivalent trials | 1120 (308) | 1162 (290) | 0.83 (0.24) | 0.88 (0.15) |
| Univalent trials in conflict blocks | 1025 (203) | 1012 (178) | 0.91 (0.8) | 0.90 (0.6) |
| Univalent trials in pure blocks | 967 (159) | 981 (156) | 0.91 (0.6) | 0.90 (0.7) |

following bivalent stimuli and overall RTs in purely univalent blocks. This is a standard analytical approach used for this paradigm (e.g. Grundy & Shedden, 2014a).

## Results

Scores from the background measures by language group are reported in Table 1. One-way ANOVAs showed that bilinguals and monolinguals were well matched on Raven's nonverbal reasoning, $F < 1$, gender, $F < 1$, age, $F(1, 78) = 3.03$, $p = .09$, and SES, $F < 1$. Scores on the PPVT did differ between groups, with monolinguals outperforming bilinguals, $F(1, 78) = 13.84$, $p < .001$, $\eta_p^2 = 0.151$, a pattern consistent with the literature (Bialystok *et al.*, 2010). As expected, bilinguals had significantly higher levels of L2 understanding, $F(1, 78) = 115.58$, $p < .001$, $\eta_p^2 = 0.597$, speaking, $F(1, 78) = 77.56$, $p < .001$, $\eta_p^2 = 0.499$, and L2 practice/exposure, $F(1, 78) = 142.08$, $p < .001$, $\eta_p^2 = 0.646$, than did monolinguals on the LSBQ, validating the group assignment.

**Table 3** *Mean RTs and proportion correct (with standard deviations) for univalent trials used to calculate post-conflict (bivalency) effects at each bin of trial positions following conflict*

| | Reaction times (ms) | | Proportion correct | |
|---|---|---|---|---|
| | Monolinguals | Bilinguals | Monolinguals | Bilinguals |
| Pure blocks | 967 (159) | 981 (156) | 0.91 (0.6) | 0.90 (0.7) |
| Conflict block | | | | |
| Trials 1/2 | 1064 (278) | 1090 (253) | 0.91 (0.11) | 0.91 (0.12) |
| Trials 3/4 | 1030 (290) | 1017 (266) | 0.90 (0.16) | 0.89 (0.14) |
| Trials 5/6 | 1016 (290) | 991 (297) | 0.89 (0.18) | 0.91 (0.16) |
| Trials 7/8 | 1024 (290) | 1009 (348) | 0.92 (0.15) | 0.89 (0.20) |
| Trials 9/10 | 932 (278) | 999 (272) | 0.90 (0.22) | 0.92 (0.17) |
| Trials 11/12 | 1085 (424) | 967 (342) | 0.91 (0.21) | 0.91 (0.20) |

Mean accuracy and reaction time (and standard deviations) in the bivalency task for trial type and group are reported in Table 2. For overall accuracy, the ANOVA revealed a significant effect of trial type, $F(2, 78) = 4.97$, $p = .01$, $\eta_p^2 = 0.060$, whereby participants performed more poorly on bivalent trials than on univalent trials in conflict blocks, $F(1, 79) = 4.65$, $p = .03$, $\eta_p^2 = 0.056$, and univalent trials in pure blocks, $F(1, 79) = 5.62$, $p = .02$, $\eta_p^2 = 0.066$; the two types of univalent trials did not differ in from each other, $F < 1$. The effect of group and the interaction term did not reach significance, $F$s $< 1.2$.

For overall RTs, the ANOVA revealed a significant effect of trial type, $F(2, 156) = 32.38$, $p < .001$, $\eta_p^2 = 0.293$, whereby RTs to bivalent trials were longer than RTs to univalent trials in conflict blocks, and both of these trial types were longer than RTs to univalent trials in pure blocks (all $p$s $< .001$). The effect of group and the interaction term did not reach significance, both $F$s $< 1$.

Table 3 presents RTs and accuracy from the univalent trials that were used to calculate post-conflict effects. Post-conflict effects were calculated as the difference in performance between bins following bivalent stimuli and overall performance in purely univalent blocks. The post-conflict effect analysis for accuracy did not reveal any statistically significant effects, all $F$s $< 1.2$. This was expected, given that the bivalency effect is an RT phenomenon and does not show reliable accuracy effects (Meier & Rey-Mermet, 2012).

Figure 2 displays post-conflict RT effects by language group. The post-conflict effect is the RT difference between responses to univalent trials following a bivalent trial and the overall mean RT for univalent trials in the pure blocks. A two-way ANOVA revealed a significant

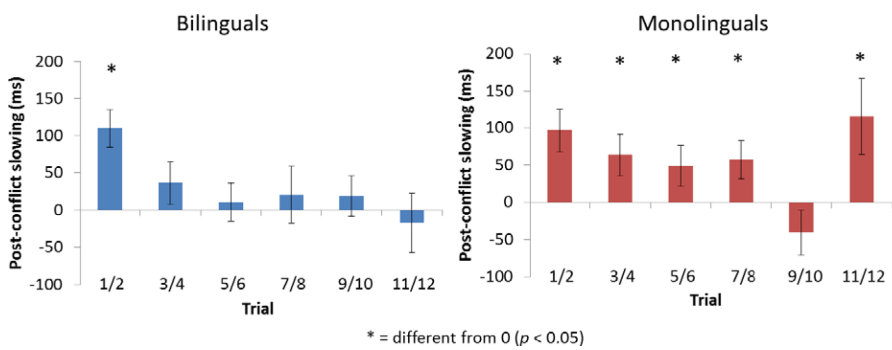


**Figure 2** *Post-conflict slowing (bivalency) effects for monolingual and bilingual children. Asterisks indicate where the post-conflict slowing effect is significantly different from 0.*

effect of trial position, $F(5, 390) = 3.07$, $p = .01$, $\eta_p^2 = 0.038$, and a significant trial position by group interaction, $F(5, 390) = 2.30$, $p = .04$, $\eta_p^2 = 0.029$. To understand this interaction, the trajectory of the post-conflict slowing effect was examined separately for each group. For bilinguals, trials immediately following bivalent stimuli (i.e. trials1/2) showed a larger bivalency effect than the rest of the trial positions (all $p$s < .04), which did not differ from each other (all $p$s > .2). For monolinguals, none of the trial positions differed from the first trial position (all $p$s > .2), with the exception of trial position 9/10 that differed from the rest (all $p$s < .02). This pattern indicates that the bilinguals had recovered to their baseline RT by Trial 3 but monolinguals had not.

The interaction was further examined by determining whether or not the post-conflict slowing effect was significantly different from 0 at each bin for each group (cf. Grundy & Shedden, 2014a, 2014b). If the effect was not different from 0, then the conflict created by the bivalent stimulus had no effect on current performance. For bilinguals, the post-conflict slowing effect was significant immediately following bivalent stimuli (Trials 1/2: $t(39) = 4.27$, $p < .001$), but did not differ from 0 on subsequent trials ($t$s < 1.3). For monolinguals, the effect was significantly different from 0 at five of the six trial pair positions (Trials 1/2: $t(39) = 3.35$, $p = .001$; Trials 3/4: $t(39) = 2.28$, $p = .02$; Trials 5/6: $t(39) = 1.81$, $p = .04$; Trials 7/8: $t(39) = 2.23$, $p = .02$; Trials 9/10: $t(39) = -1.35$, $p = .19$; Trials 11/12: $t(39) = 2.26$, $p = .02$). Thus, monolingual performance continued to be influenced by the presence of the bivalent stimulus.

## Discussion

Monolingual and bilingual children who were comparable on a range of background measures completed a bivalency effect task to determine the effect of conflict from an occasional bivalent stimulus on performance. Three important findings emerged. First, examination of overall RTs and accuracy scores across the experimental blocks revealed no group differences between monolingual and bilingual children. This is the analytic approach typically used in research comparing groups of participants (cf. Duñabeitia *et al.*, 2015). Second, a post-conflict slowing effect was present in all children, showing that this type of cognitive adjustment develops early and is sustained into adulthood. Third, examination of a more fine-grained trial-by-trial analysis revealed this effect to be longer lasting in monolinguals than it was for bilinguals, suggesting that bilingual children disengage attention from previous conflict more rapidly than their monolingual peers.

The finding that bilingual and monolingual children did not show overall RT or accuracy differences is consistent with some recent studies that also do not show overall RT or accuracy differences between monolinguals and bilinguals on conflict resolution tasks. In those studies, absence of an overall difference in RT has been used as an argument against the idea that linguistic experience dealing with conflict can lead to domain-general executive function adaptations and transfer to non-linguistic tasks. For example, Duñabeitia *et al.* (2015) examined performance on two versions of a Stroop task and found no difference between monolingual and bilingual children in terms of RT or accuracy. From this, the authors concluded that there is no bilingual advantage on simple conflict tasks. However, the results of the present study demonstrate that mean RTs during simple conflict tasks do not always provide sufficiently sensitive information about important group differences, even when these differences exist. As in the studies by Duñabeitia *et al.* (2015) and Gathercole *et al.* (2014), RTs to conflict trials did not differ between groups, but the lasting effects of conflict on subsequent performance were more revealing. A more fine-grained analysis is sometimes necessary to reveal the subtle but reliable adaptations in processing that exist between monolingual and bilingual children.

Bilinguals constantly encounter conflict in their environments as a consequence of the joint activation of both languages, so rapid disengagement from the current target language would be adaptive for processing relevant information in the environment and avoiding interference with subsequent task performance. The current study demonstrates that this aspect of EF develops early. Furthermore, there is preliminary evidence that bilingual adults also show a disengagement advantage (Mishra, Hilchey, Singh & Klein, 2012), indicating that these adaptations in disengagement of attention are sustained over time.

The monolingual children did not show a post-conflict slowing effect at trial position 9/10, but this is not surprising given the smaller number of trials and corresponding increased variability in later trial positions. It is more informative to examine the overall pattern of results: monolinguals showed post-conflict slowing effects at five out of the six trial positions, and these five trial positions did not differ from each other. In contrast, bilinguals only showed a post-conflict slowing effect immediately following conflict, after which none of the trial positions differed significantly from zero or from each other. Put another way, bilinguals quickly recovered from the effect of conflict and returned to baseline levels of performance.

There are general theoretical implications of the present work. This study is the first to report a robust post-conflict slowing effect among children. The bivalency effect is problematic for many current models of cognitive control (for discussion of these issues, see Grundy & Shedden, 2014a, 2014b; Meier *et al.*, 2009; Woodward *et al.*, 2003). For example, according to the conflict monitoring account (Botvinick *et al.*, 2001; Kerns, Cohen, MacDonald, Cho, Stenger *et al.*, 2004), the presence of a conflict trial is detected by the anterior cingulate cortex (ACC), which sends a signal to other centers such as the dorsolateral prefrontal cortex to enhance focus on task-relevant features on subsequent trials. Behaviorally, this leads to better performance on subsequent trials in which the task-relevant feature is the same. By this account, a colored symbol (i.e. conflict trial) in the present experiment should lead to an increased focus on the size of the symbol to facilitate performance on subsequent size judgments, but this is the opposite of what is found; children are slower on size judgments following conflict. Many associative models of cognitive control rely on an overlap between stimulus and/or response features between tasks to drive performance (e.g. negative priming; Lanoë, Vidal, Lubin, Houdé & Borst, 2016; Rothermund, Wentura & De Houwer, 2005; Tipper, 1985), but these theories cannot explain why the bivalency effect is observed even on trials in which no stimulus or response features are shared with conflict trials (e.g. parity trials in the present experiment; see Rey-Mermet & Meier, 2012, for slowing even when each task has its own response buttons). For these reasons, the bivalency effect is believed to index a unique adjustment in cognitive control (Grundy & Shedden, 2014a, 2014b; Meier & Rey-Mermet, 2012), but until now it has only been examined with adults. It remained possible that this form of control only developed after maturation of the brain, but the present results from 7-year-old children suggest instead that it is an adaptation that develops early and is sustained over time. This extension of the effect to children is important because the ACC is a critical center for the bivalency effect (Grundy & Shedden, 2014b; Woodward, Metzak, Meier & Holroyd, 2008), but the ACC is not fully developed until late adolescence or early adulthood (Davies, Segalowitz & Gavin, 2004; Diamond, 2002; Ladouceur, Dahl & Carter, 2007; Luna & Sweeney, 2004). The present results suggest that the ACC does not need to be fully developed to implement the type of control observed here. Importantly, research with adults has shown that a key brain region for understanding better performance by bilinguals on executive function tasks is the structure and function of the ACC (Abutalebi, Della Rosa, Green, Hernandez, Scifo *et al.*, 2012). It would be fruitful, therefore, to pursue these speculations with neuroimaging evidence from children. It might be that the *functional* adaptations of the ACC and related areas develop early despite the relative immaturity of *structural* changes.

In previous research examining differences between monolinguals and bilinguals performing EF tasks, the focus has frequently been on the role of inhibition or inhibitory control. As discussed earlier, however, the inhibition account provides a poor fit with much of the data. The present results suggest an alternative means by which monolingual and bilingual children process information differently in their environments. Rather than focusing on inhibition, the account focuses on general attention ability and control. Specifically, the proposal is that the processes used to disengage attention from conflict may develop differently in these groups.

The explanation for processing differences between monolinguals and bilinguals must account for differences in the ability of individuals in these two groups to manage or resolve conflict. Inhibition and disengagement of attention potentially offer complementary explanations for how this is achieved. In the inhibition account, the interfering or irrelevant option is suppressed so that it does not interfere with current processing. However, evidence from bilingual language use indicating constant effects of the non-target language and the current evidence for the continued influence of the bivalent stimulus on subsequent performance show that suppression is not a sufficient explanation. In contrast, the attention account evaluates the ability to actively focus attention where needed in response to a goal, a process that becomes more effortful in the context of conflicting or distracting alternatives.

The proposal is that the experience of constantly focusing attention on the target language and disengaging from the previous context strengthens these attention abilities more broadly. Thus, bilinguals develop more efficient attentional resources to disengage attention and recover from conflict once other mechanisms have already been implemented to resolve said conflict. Even prior to productive language use, infants in bilingual environments must deal with management of attentional resources in order to learn how to represent different objects and maintain the distinction between the two linguistic systems to which they are exposed.

The ability to rapidly and effectively disengage attention from conflict in order to focus on relevant cues is likely only one mechanism in an array of processes that contribute to performance differences between monolinguals and bilinguals. Evidence for identifying these attention processes requires more detailed designs and analyses than those typically used in this research that are based on overall averages of RT or accuracy across conditions in a paradigm. However, such designs are essential in order to uncover the processing differences that shape monolingual and bilingual minds from childhood.

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