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Executive functions and inhibitory control in multilingual children: Evidence from second-language learners, bilinguals, and trilinguals

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ABSTRACT

In two experiments, we examined inhibitory control processes in three groups of bilinguals and trilinguals that differed in nonnative language proficiency and language learning background. German 5- to 8-year-old second-language learners of English, German–English bilinguals, German–English–Language X trilinguals, and 6- to 8-year-old German monolinguals performed the Simon task and the Attentional Networks Task (ANT). Language proficiencies and socioeconomic status were controlled. We found that the Simon effect advantage, reported in earlier research for bilingual children and adults over monolinguals, differed across groups, with bilinguals and trilinguals showing enhanced conflict resolution over monolinguals and marginally so over second-language learners. In the ANT, bilinguals and trilinguals displayed enhanced conflict resolution over second-language learners. This extends earlier research to child second-language learners and trilinguals, who were in the process of becoming proficient in an additional language, while corroborating earlier findings demonstrating enhanced executive control in bilinguals assumed to be caused by continuous inhibitory control processes necessary in competition resolution between two (or possibly more) languages. The results are interpreted against the backdrop of the developing language systems of the children, both for early second-language learners and for early bilinguals and trilinguals.

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Introduction

Recent research has demonstrated that when bilinguals and second-language learners use one language only, both languages are active and may compete for selection (e.g., Costa, Miozzo, & Caramazza, 1999; Hermans, Bongaerts, de Bot, & Schreuder, 1998; Hermans, Ormel, Van Besselaar, & Van Hell, 2011; Kroll, Bobb, & Wodniecka, 2006; Poarch & Van Hell, 2012). Managing two languages at the same time requires a control mechanism that resolves the competition between the two languages effectively in order to use one language, the intended language, for communication. Such an inhibitory control mechanism for bilingual lexical access has been proposed by, for example, Green (1998). In other research, it has been suggested that continuously using such a bilingual control mechanism to cope with competition between languages has more general cognitive consequences, namely enhanced cognitive control in bilingual children relative to monolingual children and adults (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004). Past research has focused on comparing bilinguals and monolinguals in various age groups, but so far it has neglected child second-language learners, whose proficiency in the second language is substantially lower than that in the native language, and trilingual children, whose proficiency in their third language is lower than that in their two native languages. By tapping into executive control processes in these distinct groups, we attempt to shed light on whether second-language learners, who could be posited between monolinguals and bilinguals on a ''language development continuum'', and trilinguals, who could be posited beyond bilinguals, show the same cognitive enhancement as bilinguals have been shown to do.

In this article, we report two experiments in which we examined to what extent early second-language learners, bilingual children, and trilingual children, with different levels of proficiency in their second and third languages and with different language learning backgrounds, display differences in cognitive control in two tasks of executive function. More specifically, we aimed at determining whether second-language learners already showed enhanced cognitive control over monolinguals, mirroring the need to control two languages, and whether trilingual children, due to their possibly greater need to monitor and control multiple languages, showed equal or advanced cognitive control compared with bilinguals. Before reporting these experiments, we briefly review the available evidence suggesting that during second-language (L2) usage, the first language (L1) is also active and, consequently, bilingual speakers need to control their languages to prevent interference. This mechanism, it is assumed, has consequences in the nonverbal domain and may confer enhanced executive functions in bilinguals.

Language control in bilinguals

Although both a bilingual's languages are active, bilingual speakers are able to separately use their two languages. Thus, bilingual speakers evidently display the capacity to choose between their two languages and produce only one; this process calls for some kind of language control mechanism (Costa, La Heij, & Navarrete, 2006; Costa, Santesteban, & Caño, 2005; Costa et al., 1999; Green, 1998; Kroll et al., 2006). Depending on the bilingual speaker's interlocutor, one language, the target language, needs to be activated over the other, the nontarget language.

Proposals on how bilinguals deal with multiple languages so far all posit an attentional control mechanism at the base of this process. Green (1998), for example, suggested that bilingual language production was possible because the nontarget language representations were inhibited and their activation was suppressed. Meuter and Allport (1999) argued similarly, based on their findings of asymmetrical switching costs in a language switching study with low-proficient bilinguals (see also Costa & Santesteban, 2004, and Costa, Santesteban, & Ivanova, 2006, for studies with highly proficient bilinguals and more symmetrical switching costs). This asymmetry in switching was interpreted as indicating that stronger inhibition was necessary to suppress the L1 language representations during L2 usage than to suppress the L2 language representations during dominant L1 usage (for alternative interpretations of the switching cost, see, e.g., Finkbeiner, Almeida, Janssen, & Caramazza, 2006).

Recently, there has been a shift from viewing inhibition as the single hypothesized attentional control component in bilingual language control to a more global executive functioning idea (see Bialystok, 2010, 2011; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009). Bialystok (2010),

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for example, found a bilingual advantage in 6-year-olds in conflict resolution tasks even when processing complex stimuli that involved no explicit inhibitory component. Using two sets of conflict tasks with varying executive demands and, critically, varying involvement of inhibition, Bialystok was able to tease apart whether the bilingual advantage could be traced solely to the inhibition component or whether it also involved other aspects of executive control such as shifting and updating. The results are interpreted as indicative of a bilingual advantage in executive control components that are related to monitoring and shifting, which extends the previously suggested inhibition and conflict resolution as responsible factors. Furthermore, in a study specifically tapping into the three core executive control components working memory, inhibition, and shifting, Bialystok (2011) obtained results indicating that the bilingual advantage may stem from an enhanced general executive control network and a more effective recruitment of combined executive control components in bilinguals.

Given that language acquisition histories may have variable repercussions in the domain of language control and, thus, possibly more generally on cognitive control, a focus on the multilingual children's onset of L2 acquisition, relative language proficiencies, and intensity and length of language exposure seems pertinent at this point. Children, in contrast to adults, are still developing an effective control mechanism in order to keep their languages apart. Research has shown that when bilinguals use one language, the other language is also active (for a review, see Van Hell & Tanner, 2012). Such cross-language activation has been shown to be bidirectional (i.e., L1 on L2 and vice versa) in, for example, highly proficient bilingual children exposed to German and English from birth (Poarch & Van Hell, 2012), making continuous control of the two languages necessary to avoid intrusion of the nontarget language. In contrast, child second-language learners with low L2 proficiency have been shown to display unidirectional cross-language activation (i.e., only L1 on L2; e.g., Brenders, Van Hell, & Dijkstra, 2011; Poarch & Van Hell, 2012), which implies that low-proficiency L2 speakers do not need to exert much effort to control their two language systems. Thus, if one assumes a multilingual continuum, at one end there are children who are exposed to and develop two (or more) languages from birth onward (De Houwer, 2009; Genesee & Nicoladis, 2006) and who show various degrees of language mixing (see, e.g., Lanza, 1997; Tracy, 2000), from which follows that they need to actively control their languages for successful communication. Further along the continuum, one could place child second-language learners who are exposed to a second language between approximately 3 and 6 years of age in immersion environments (thus, substantially later than the first-mentioned group of children). At the other end of the continuum, we have monolingual children who learn their second language in classroom settings at a point when their L1 is already fairly well developed (after 6 years of age) and who have limited exposure to the second language and do not (yet) have a long history of needing to control their two language systems. These different language learning histories, particularly regarding L2 acquisition, are related to how much practice these children have accrued in controlling their language systems, which, critically, may have different repercussions on more general cognitive control.

Consequences of bilingualism on executive functions

If inhibitory processes are indeed responsible for conferring language control to bilinguals, then one could assume that nonlinguistic areas in bilinguals requiring inhibitory control might also be affected. Previous research suggests that repeated and regular use of two languages, and the associated control over two languages, has an impact on executive functions in bilingual speakers. This has been shown particularly with young children and elderly adults, whose performance differed from matched monolinguals in executive functions tasks such as the Simon task and an antisaccade task (Bialystok, Craik, & Ryan, 2006; Bialystok & Shapero, 2005; Bialystok et al., 2004; Craik & Bialystok, 2005; Martin-Rhee & Bialystok, 2008). Compared with monolinguals, child and young adult bilinguals have also been shown to display enhanced executive control on the Attentional Networks Task (Costa, Hernández, & Sebastián-Gallés, 2008; Yang, Yang, & Lust, 2011) and greater conflict resolution through reactive inhibition of irrelevant information (Colzato et al., 2008). Whereas in the studies of both Costa et al. (2008) and Colzato et al. (2008) the adult bilinguals tested had grown up with and been immersed in two languages since early childhood, Carlson and Meltzoff (2008) tested bilingual kindergarten children and found that they outperformed monolingual and immersed L2 learners in tasks

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measuring conflict resolution, one of them being the Attentional Networks Task. The authors suggested that the need to switch between and control their two languages had honed the bilingual children's executive functions. Furthermore, the 6 months of immersion for the L2 learners had not been a sufficient period of exposure to induce an advantage in executive functioning over the monolingual group.

In a study exploring cognitive control in late adult bilinguals, Festman, Rodriguez-Fornells, and Münte (2010) asked participants to perform a battery of tests tapping into executive functions, including the Tower of Hanoi, Divided Attention, and Go/No-Go tasks. The results indicated that participants who (indirectly) exhibited stronger language control as measured by a bilingual picture-naming task also performed better on the executive function tests. Thus, it seems that needing to extensively control the interference between two languages also enhances late bilinguals' nonlanguage executive control and that this is modulated by the strength of their language control abilities.

Overall, bilinguals have been found to display a cognitive advantage over monolinguals in various conflict resolution and distracter inhibition tests, which is thought to emerge from repeated and regular practice of language control. This is supported by imaging studies (e.g., Hernandez & Meschyan, 2006) in which language control and executive functions were shown to be subserved by the same brain areas even at lower levels of L2 proficiency, suggesting a close relationship between bilingual language use and executive control (for a recent meta-analysis, see Luk, Green, Abutalebi, & Grady, in press).

However, in a review of studies on the bilingual advantage in executive control mechanisms, Hilchey and Klein (2011) pointed out that many of the studies on cognitive advantages in inhibitory control processes have used differing designs and methodologies, and the results obtained do not unequivocally converge on the same pattern. This pattern is supposed to converge on two bilingual advantages: (a) an overall (global) reaction time (RT) effect showing a bilingual advantage in response latencies in congruent and incongruent conditions and (b) an interference effect as indexed by the magnitude of difference between congruent and incongruent conditions showing a bilingual advantage. In this regard, the authors also commented on the inconsistent patterns of bilingual advantages found in children and in young, middle-aged, and elderly adults. Thus, it should be informative to take a closer look at the group in which global RT and interference effect advantages have been so elusive, namely children. Moreover, the link between varying language learning histories and levels of L2 proficiency, on the one hand, and inhibitory control enhancement, on the other, could be explored in more detail not only by contrasting bilinguals and monolinguals, as has been done previously, but also by examining second-language learners and trilinguals.

The current study

Building on studies with monolingual and bilingual children (e.g., Martin-Rhee & Bialystok, 2008) and adults (e.g., Costa et al., 2008, 2009), we investigated nonlinguistic effects of language control in early second-language learners, bilinguals, and trilinguals. All children had had extensive contact with at least two languages in an immersion environment at home and/or at kindergarten/school.

All children completed the Simon task (Simon & Rudell, 1967) and the Attentional Networks Task (ANT) (Rueda, Fan, et al., 2004) (see "Materials" sections for detailed overviews). The Simon task and the ANT are conflict processing tasks that are used to assess the attentional component of executive control, a component that involves two executive control processes: conflict monitoring, which includes detection of conflict and preparation of specific subsequent actions, and conflict resolution, which includes, for example, inhibitory control, planning, and rule holding (Posner & Fan, 2004). Whereas the Simon task is a forced-choice task with two alternative responses in which participants need to choose between targets that appear left or right of a fixation stimulus, the ANT asks participants to respond to the direction of a center stimulus (pointed to the left or right) that appears after various fixation stimuli. Thus, both tasks, after activating conflicting representations, induce participants to make a decision between two competing responses and then make the appropriate response.

There are critical differences between the Simon task and the ANT. First, to perform the Simon task, participants need to keep in mind and heed the stimulus–response rule that, depending on which color the stimulus is, the respective button needs to be pressed. In contrast, for the ANT, the component

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of keeping in mind a stimulus–response rule is much less pronounced as, depending on which direction the critical stimulus points, the corresponding left or right button needs to be pressed. Thus, different attentional components are addressed in these two tasks. Second, in the Simon task a prepotent response needs to be suppressed in that the response should be in accordance with the stimulus–response rule and not the stimulus location, whereas in the ANT both target and flankers call for the same response type. Third, the Simon task uses on-screen position as a distracter and color as a target dimension, which means that there are different formats used, whereas the ANT employs the same format in the form of arrows for both dimensions.

The Simon task and the ANT are assumed to be particularly appropriate for assessing potential cognitive differences between monolinguals and bilinguals (see, e.g., Bialystok, Martin, & Viswanathan, 2005; Carlson & Meltzoff, 2008) because they rely only to a minimal extent on language and memory processes that may interact with bilingualism or multilingualism. The current study provides more detailed insights into the cognitive benefits of dealing with multiple languages regularly by also including multilinguals who have been understudied, namely L2 learners and trilinguals.

Predictions

If being subjected to two or more languages on a daily basis (and needing to control the use of these languages depending on one's interlocutor and situational demands) conferred advantages in executive control of participants, then the following predictions may be made:

1. In both tasks, the magnitude of the difference between congruent and incongruent trials should be largest for monolinguals, smaller for L2 learners, and smallest for bilinguals and trilinguals. This is based on the presupposition that bilinguals and trilinguals have accrued the most extensive training in language control, whereas L2 learners have accrued less and monolinguals have accrued none.
2. In both tasks, bilinguals have been found to outperform monolinguals in overall response times in inhibitory control tasks (e.g., in the Simon task: Bialystok, 2006; in the ANT: Costa et al., 2008), even in those components that do not induce conflict (e.g., congruent trials), which is assumed to be linked to enhanced monitoring processes in bilinguals. In tasks with congruent and incongruent trials, participants need to continuously monitor the stimuli for potential conflict and prepare the appropriate response, a process that draws on the executive control network. Thus, overall response times (also called global RTs) should successively become faster from monolinguals (slowest) over L2 learners (slower) to bilinguals (faster) and trilinguals (fastest) for both congruent and incongruent trials.
3. The predictions for the alerting and orienting networks (addressed only by the ANT; see Experiment 2) are overall faster responses on trials in which an alerting cue is presented (alerting network) and on trials in which the position of the target is indicated by a cue beforehand (orienting network). As Costa et al. (2008, p. 67) pointed out, these are general predictions that do not pertain to bilinguals more than to monolinguals.

Experiment 1: Simon task

Methods

Design

A 2 (Stimulus Type: congruent or incongruent) × 4 (Language Group: second-language learners, bilinguals, trilinguals, or monolinguals) factorial design was used.

Participants

The participants were 75 children, all of whom had grown up and lived in Frankfurt, Germany. The second-language learners, bilinguals, and trilinguals attended a bilingual German–English immersion Montessori kindergarten and primary school, and the monolingual children attended a German-only primary school. The four groups of participants are described below.

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Second-language learners. These participants were 19 German second-language learners of English (mean age = 6.9 years, *SD* = 0.8, range = 5.2–7.8, 8 girls and 11 boys). They had been immersed for 1.3 years (*SD* = 0.8) and spoke standard German as their first or native language and English as their second language. None of the children had grown up with or, prior to attending the immersion program, had had any continuous exposure to a language apart from standard German since birth.

Bilinguals. These participants were 18 German–English bilingual children (mean age = 6.8 years, *SD* = 0.7, range = 5.2–8.2, 9 girls and 9 boys). Their mean length of immersion was 2.8 years (*SD* = 0.9), and they had grown up bilingually with German and English spoken at home from birth onward (8 children had a German-speaking mother and an English-speaking father, whereas 10 children had an English-speaking mother an a German-speaking father). None had had any continuous exposure to languages apart from standard German and English.

Trilinguals. These participants were 18 bilingual third-language (L3) learners of either German or English (mean age = 6.8 years, *SD* = 0.9, range = 5.2–8.1, 11 girls and 7 boys). Their mean length of immersion was 2.4 years (*SD* = 1.1). Of these 18 children, 9 had grown up bilingually with standard German and another language apart from English as dual L1 at home, and 9 had grown up with English and a language apart from German as dual L1 at home. Thus, 9 children were growing up with two languages and were exposed to L3 English at kindergarten/school at an average age of 5.2 years (*SD* = 1.7), and 9 children were early trilinguals exposed to L3 German in the environment from birth and to German and English at kindergarten at an average age of 3.2 years (*SD* = 1.3).

Monolinguals. These participants were 20 monolingual children (mean age = 7.1 years, *SD* = 0.5, range = 6.0–7.9, 9 girls and 11 boys). They spoke standard German as their first and native language and had not yet begun second-language instruction. None had had any continuous exposure to a language save standard German.

Children's language proficiencies in German and English were assessed by the Tests for Reception of Grammar (TROG) for English (Bishop, 2003) and for German (Fox, 2006) (see Materials section for detailed descriptions). Although the four groups of children did not differ significantly in German, they did so in English, as expected. Furthermore, only the bilinguals showed balanced German–English proficiencies, whereas the other groups' proficiencies were higher in German than in English. Table 1 displays the children's proficiencies and length of immersion.

Children's parents signed a consent form and filled in a questionnaire on their education levels and their children's language background. Parents' ratings of their children's proficiency in German and English, using a 5-point scale (1 = *no proficiency* to 5 = *native-like proficiency*), yielded no significant differences for German but did so for English. Finally, all children were considered by their parents to be more proficient in German than in English, even the bilinguals. Parents' education levels were considered to represent the family's socioeconomic status (SES) (e.g., Hoff, 2003); it did not differ significantly across groups, $Fs(3,71) < .10$, $p > .30$. Table 1 displays the parents' education levels.

Materials

The materials consisted of the Test for Reception of Grammar and the Simon task experimental stimuli.

Test for Reception of Grammar. The Test for Reception of Grammar, developed for English (TROG-2) by Bishop (2003) and for German (TROG-D) by Fox (2006), measures children's receptive language proficiency. The two tests were administered with a 2-week time lag between tests, in order to prevent any spillover effects, and 2 weeks before the first experiment took place. (Note that half of the materials differ in the two tests.).

Simon task. In the Simon task (Bialystok et al., 2004; Simon & Rudell, 1967), a series of colored squares is presented on the screen one at a time. The squares vary in color (in this study, blue or red) and location on the screen (left of fixation, right of fixation, or at fixation). Participants were told to press a left or right button colored accordingly on a button box with their left or right index finger in response to

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Table 1
Characteristics of participant groups.

Characteristic	Group			
	L2 learners	Bilinguals	Trilinguals	Monolinguals
Age (years)	6.9 (0.8)	6.8 (0.7)	6.8 (0.9)	7.1(0.5)
Gender (girls:boys)	8:11	9:9	11:7	9:11
Length of bilingual immersion (years)	1.3 (0.8)	2.6 (0.9)	2.0 (1.1)	N/A
Mother's education[a]	3.5	3.2	3.7	3.5
Father's education[a]	3.5	3.3	3.6	3.6
Proficiency in L1				
TROG German (standard score[b])	113.7 (13.1)	108.8 (18.9)	105.0 (18.5)	114.3 (13.5)
	$F(3,71) = 1.40$, $p > .10$, Tukey's HSD post hoc comparison, all $ps > .10$			
Parents' rating[c] German	4.9 (0.3)	4.7 (0.5)	4.7 (0.6)	4.9 (0.3)
	$F(3,71) = 1.43$, $p > .10$, Tukey's HSD post hoc comparison, all $ps > .10$			
Proficiency in L2				
TROG English (standard score)	80.8 (14.0)	112.3 (13.2)	96.1 (18.1)	56.4 (1.1)
	$F(3,71) = 63.36$, $p < .001$, Tukey's HSD post hoc comparison, all $ps < .005$			
Parents' rating[c] English	1.5 (0.6)	4.1 (0.6)	3.4 (0.9)	1.0 (0.0)
	$F(3,71) = 119.20$, $p < .001$, Tukey's HSD post hoc comparison, all $ps < .001$ (save L2 learners vs. monolinguals, $p < .04$)			
Proficiency comparison				
TROG German and English	$p < .05$	$p > .10$	$p < .05$	$p < .05$
Parents' rating German and English	$p < .01$	$p < .01$	$p < .01$	$p < .01$

Note: Standard deviations are in parentheses.
[a] Education quantified using a 5-point scale (1 = *middle school,* 2 = *high school graduate,* 3 = *bachelor's degree,* 4 = *master's degree,* 5 = *doctoral degree*).
[b] German standard score calculated on the basis of the TROG-D T-score in a range of 20 to 80 ($M = 50$, $SD = 10$) and, for easier comparison, transferred to the TROG-2 English standard score range of 55 to 145 ($M = 100$, $SD = 15$). Formula for converting T-scores into standard scores: $b = \{[(a - a \text{ mean})/a \text{ SD}] \times b \text{ SD}\} + b \text{ mean}$, where a = T-score and b = standard score.
[c] Parents' rating follows a 5-point language proficiency scale (1 = *no proficiency,* 2 = *low proficiency,* 3 = *moderate proficiency,* 4 = *moderate to high proficiency,* 5 = *native-like proficiency*).

the color of the square on the screen irrespective of the square's location. In the *congruent trial,* the square appeared on the same side as the correct button response (e.g., a square on the right of fixation that required a right index finger button box response—thus, a response in which stimulus and response locations match). In the *incongruent trial,* the square appeared on the opposite side of the correct button response (e.g., a square on the right of fixation that required a left hand button box response). In the *central trial,* the square appeared at fixation and, thus, was neither incongruent nor congruent with the correct response location.

Extensive evidence has been reported (e.g., Simon & Rudell, 1967) showing that response times are longer on incongruent trials than on congruent trials caused by the effect of a mismatch between the spatial location of stimulus and location of response, also called the Simon effect. The magnitude of this effect is assumed to reflect a participant's ability to inhibit the prepotent response evoked by the spatial location of the stimulus.

Apparatus and procedure

The experiment was presented on a laptop Gateway Solo 2150 computer with a 12-inch monitor. The experimental tasks were programmed and run using E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Response latencies were measured using an E-Prime serial response button box (Schneider, 1995). The experimental procedure was based on that used by Bialystok et al. (2004). Each trial started with a fixation (+) displayed in the center of the screen for 800 ms, followed by a blank for 250 ms. Then, a blue or red square appeared at the center ($x = 0.00°$, $y = 0.00°$), on the left ($x = 0.02°$, $y = 0.36°$), or on the right ($x = 0.82°$, $y = 0.36°$) side of the screen, remaining there for 1000 ms if there was no response. Participants were instructed to press the left button box key (color-coded "blue") when they saw a blue square and to press the right button box key (color-coded "red") when they saw a red square. Timing began at stimulus onset, and the participant's response terminated the stimulus. Before the onset of the next trial, a 500-ms blank was shown. Of the 126 experimental trials, a third presented the square centrally (neutral trials), a third presented the square on the same side as the associated response key (congruent trials), and a third presented the square on the opposite side (incongruent trials). These trials were presented in random order.

Participants were tested individually and were seated in a dimly lit room approximately 50 cm from the monitor. They were asked to press the respective button as quickly and as accurately as possible. The Simon task was set up in four blocks, the first of which consisted of 24 practice trials. These trials were used to familiarize the participants with the experimental procedure and, if necessary, to give them additional instructions before proceeding. Each of the three experimental blocks (blocks of 42 stimuli each) was started with the press of a button by the researcher. The entire experiment lasted approximately 10 min.

Results and discussion

For each participant, mean response latencies (RT) and mean percentages of errors were calculated for the Simon task. Trials after incorrect responses were excluded from the RT analysis and error rate (ER) analysis. Outliers with RTs shorter than 200 ms or longer than 2.5 standard deviations (SDs) above the participant's mean (second-language learners = 3.6%, $SD = 1.7$; bilinguals = 3.3%, $SD = 1.9$; trilinguals = 3.1%, $SD = 1.5$; monolinguals = 3.5%, $SD = 1.8$) were also excluded from the RT analyses.

First, a 2 (Stimulus Type: congruent or incongruent) $\times$ 4 (Language Group: second-language learners, bilinguals, trilinguals, or monolinguals) analysis of variance (ANOVA) was run, with stimulus type as a within-participant variable and language group as a between-participant variable. Then, one-factor (stimulus type) repeated measures ANOVAs were performed on the mean RTs and ERs separately for each group, treating stimulus type as a within-participant variable. The resulting means and SDs are presented in Table 2.

The RT data yielded a significant main effect of stimulus type, $F(1,71) = 480.05$, $MSE = 534$, $p < .001$, $\eta_p^2 = .87$, indicating different response latencies for incongruent stimuli relative to congruent stimuli. The main effect of language group was not significant, $F(3,71) < 1.00$, $p > .10$, but the interaction between stimulus type and language group was significant, $F(3,71) = 3.31$, $p = .025$, $\eta_p^2 = .12$, indicating that the Simon effect (i.e., the magnitude of the difference between congruent and incongruent trials) differed significantly between groups. Post hoc Tukey's HSD (honestly significant difference) comparisons of the magnitude of the Simon effect showed that monolinguals displayed a significantly greater effect than trilinguals ($p = .016$) and a marginally significantly greater effect than bilinguals ($p = .062$). None of the other pairs differed significantly ($ps > .10$).

The error data analysis yielded a significant overall effect of stimulus type, $F(1,71) = 67.11$, $MSE = 31$, $p < .001$, $\eta_p^2 = .49$, no main effect of language group, $F(3,71) < 1.00$, $p > .10$, and no interaction between stimulus type and language group, $F(3,71) < 1.00$, $p > .10$, indicating different error rates for incongruent stimuli relative to congruent stimuli—the Simon effect—but no significant differences between the groups in regard to the magnitude of the Simon effect. Finally, one-factor ANOVAs on each of the four groups separately showed significant Simon effects in both RTs (all $ps < .001$) and ERs (all $ps < .004$).

The results obtained in Experiment 1 indicate that the trilinguals, and marginally the bilinguals, display conflict resolution on this task superior to that of the monolinguals (Prediction 1), which is manifested by a smaller effect magnitude for the bilinguals and the trilinguals in the RT analysis.

Table 2
Mean RTs (ms) and ERs (%) for Simon task by language group in Experiment 1.

	RT (ms)				ER (%)			
	L2 learners	Bilinguals	Trilinguals	Monolinguals	L2 learners	Bilinguals	Trilinguals	Monolinguals
Center	685 (101)	670 (85)	686 (108)	689 (100)	11.0 (8.6)	7.7 (3.6)	11.5 (11.8)	9.1 (4.1)
Incongruent	752 (106)	720 (90)	735 (114)	745 (113)	15.9 (10.1)	14.8 (4.3)	16.4 (8.4)	15.0 (6.4)
Congruent	662 (104)	646 (81)	666 (110)	647 (107)	8.7 (5.3)	7.3 (4.0)	9.9 (9.2)	6.8 (3.2)
Effect	90	74	69	98	7.2	7.5	6.5	8.2

Note: Standard deviations are in parentheses.

We take this as an indication of enhanced cognitive control in these multilingual children caused by their need to regularly and repeatedly draw on language control processes. Remarkably, the magnitude of the Simon effect for the L2 learners did not differ significantly from that of the monolinguals, on the one hand, and that of the bilinguals and trilinguals, on the other. It is assumed that the length of immersion and L2 experience for the L2 learners might not have been sufficient to enhance their conflict resolution to differ significantly from that of the bilinguals and trilinguals or from that of the monolinguals. Finally, concerning task monitoring as measured by overall (global) RTs in the congruent and incongruent conditions (Prediction 2), none of the groups differed significantly, indicating no monitoring global RT advantage for any of the groups.

Given that conflict resolution differences had been found in Experiment 1 between monolinguals, on the one hand, and bilinguals and trilinguals, on the other, with second-language learners holding the middle ground, the main focus of Experiment 2 was to explore whether the second-language learners, bilingual children, and trilingual children would perform similarly in an alternative task that measures not only conflict but also other components of executive control (the Attentional Networks Task). Having established that the second-language learners did not differ significantly from the monolinguals, and in line with the focus of this study on cognitive control in multilingual children with different language proficiencies and language learning histories and uses, we chose to disregard the monolinguals and to focus instead on comparing the second-language learners' performance with that of the bilinguals and trilinguals. Therefore, the ANT was administered with the second-language learners, bilingual children, and trilingual children 6 to 8 months later.

Experiment 2: Attentional Networks Task

Methods

Design

A 4 (Cue Condition: no cue, double cue, center cue, or spatial cue) $\times$ 2 (Flanker Type: congruent or incongruent) $\times$ 3 (Language Group: second-language learners, bilinguals, or trilinguals) factorial design was used.

Participants

The participants were 56 children comprising three language groups: 19 second-language learners, 19 bilinguals, and 18 trilinguals. Note that these children were the same as those in Experiment 1 save 1 additional bilingual matched in age and proficiency to all other participants.

Experiment 2 was conducted 6 to 8 months after Experiment 1. Thus, second-language learners (mean age = 7.6 years, *SD* = 0.8), bilinguals (mean age = 7.3 years, *SD* = 0.7), and trilinguals (mean age = 7.5 years, *SD* = 1.0) were correspondingly older than those in Experiment 1.

Materials

The materials consisted of the Attentional Networks Task experimental stimuli. The ANT, developed by Fan, McCandliss, Sommer, Raz, and Posner (2002), is a combination of a cue reaction time task (Posner, 1980) and a flanker task (Eriksen & Eriksen, 1974). The ANT has been used in a wide range of studies on attention, ranging from developmental studies (Rueda, Fan, et al., 2004; Rueda, Posner, Rothbart, & Davis-Stober, 2004) to genetic studies (Fan, Fossella, Sommer, Wu, & Posner, 2003; Fossella et al., 2002) of attention. The ANT is constructed so as to explore three distinct so-called attentional networks: executive control (monitoring and conflict resolution), alerting (attainment and maintenance of an alert state), and orienting (selection of information from sensory input). In this experiment, the child version of the ANT (Rueda, Fan, et al., 2004) was used and is based on the original version of Fan et al. (2002).

In the ANT, participants press one of two buttons on a keyboard, mouse or response box to indicate whether a central arrow displayed on the screen points to the left or right. This central arrow is flanked to the left or right by two arrows, each pointing in the same direction (congruent trial) or in the opposite direction (incongruent trial) as the target arrow (for the child version of the ANT used in this study, see "Apparatus and Procedure" section below; see also Rueda, Fan, et al., 2004). The incongruent trials tend to elicit slower responses than the congruent trials because participants need to overcome and resolve the conflict that arises between the target stimulus and the to-be-ignored flankers. It is assumed that the conflict arising in this task, the conflict effect, taps the functional properties of the executive control network. Furthermore, all congruent and incongruent trials are preceded by one of four visual cues: a double cue, no cue, a spatial cue, or a central cue (for a schematic of cue types, see Costa et al., 2009). These cues tap the so-called alerting and orienting networks. The alerting network is explored by displaying a double cue or no cue before the target stimulus; responses are slower when the target is not preceded by an alerting cue than when it is. In a final step, the orienting network is studied by displaying either a spatial cue that indicates where exactly the target stimulus will appear on the screen or a central cue that does not; responses are slower when there is a central cue that does not signal where the target will appear than when there is a spatial cue that does so.

Apparatus and procedure

The apparatus was identical to that of Experiment 1. The experimental procedure was based on that used by Rueda, Fan, et al. (2004). Each trial began with a fixation (+) at the center of the screen. The target was a yellow colored line drawing of a single fish or a horizontal row of five fish, presented below or above fixation, over a turquoise background. Participants were asked to respond according to whether the central fish was pointing to the right or left by pressing the corresponding left or right button on the button box. On incongruent trials the flanking fish pointed in the opposite direction as the central fish, on congruent trials the flanking fish pointed in the same direction as the central fish, and on neutral trials the central fish appeared without flanking fish. Each target stimulus was presented approximately 1° below or above fixation and was preceded by one of four warning cue conditions: a center cue (an asterisk is presented at the location of the fixation cross), a double cue (an asterisk appears at the locations of the target below and above the fixation cross), a spatial cue (a single asterisk is presented in the position of the upcoming target), or no cue (see Rueda, Fan, et al., 2004, pp. 1031–1032, for exact spatial information of stimuli display).

As in Experiment 1, participants were tested individually and were seated in a dimly lit room approximately 50 cm from the monitor. They were asked to place their left and right index fingers on the left and right buttons of the button box and to press the respective button as quickly and as accurately as possible. Automatic computer-generated feedback for each trial was supplied through headphones, and each session lasted approximately 15 to 20 min. The session consisted of 24 practice trials and three experimental blocks of 48 trials each. A trial represented 1 of 12 conditions in equal proportions: 3 target types (congruent, incongruent, and neutral) times 4 cues (no cue, central cue, double cue, and spatial cue).

Trials began with a fixation (+) displayed between 400 and 1600 ms with random variable duration. Afterward, on some trials a 150-ms warning cue was displayed. After the cue disappeared, a 450-ms fixation (+) appeared, followed by either the target presented alone or the target presented simultaneously with the flanker items; this remained on the screen for a maximum of 1700 ms or until a response was made by the child. The child received visual and auditory feedback after making a response by pressing a button. A correct response prompted a short animation in which the target fish blew bubbles while cheering "Woo-hoo!" An incorrect response was followed by no animation of the fish and a single tone being played.

Children were instructed to feed the hungry fish at the middle of the screen by pressing the button on the button box corresponding to the direction in which the fish was pointing. They were told that the hungry fish sometimes swam alone and sometimes swam with other fish but that they were always to feed the one in the middle. After receiving the test instructions, the experimenter remained in the room and participants started with the practice block, after which the three experimental blocks began. Between each of the four blocks, children could take a short break.

Results and discussion

For each participant, mean response latencies (RT) and mean percentages of errors were calculated. Means and SDs for all conditions are presented in Table 3. Trials after incorrect responses were

Table 3
Mean RTs (ms) and ERs (%) for ANT by language group in Experiment 2.

	Flanker								
	Congruent			Incongruent			Conflict		
	L2 learners	Bilinguals	Trilinguals	L2 learners	Bilinguals	Trilinguals	L2 learners	Bilinguals	Trilinguals
	RT (ms)								
None	899 (186)	942 (156)	909 (131)	994 (207)	973 (138)	951 (143)	95	31	43
Double	881 (223)	874 (115)	847 (154)	944 (188)	963 (134)	893 (136)	63	89	47
Center	857 (195)	904 (144)	855 (129)	962 (231)	961 (124)	929 (149)	105	58	74
Spatial	857 (219)	862 (138)	839 (132)	952 (203)	914 (129)	870 (128)	96	52	31
Alerting	18	67	62	49	10	58			
Orienting	0	42	16	9	47	58			
	ER (%)								
None	3.0 (6.2)	3.3 (6.7)	3.8 (4.7)	6.7 (7.2)	4.8 (7.2)	5.4 (6.5)	3.7	1.5	1.6
Double	2.6 (5.0)	4.1 (6.0)	2.0 (3.9)	4.8 (5.4)	4.8 (6.6)	5.8 (6.6)	2.2	0.8	3.8
Center	4.0 (5.4)	3.9 (7.0)	3.4 (4.1)	4.4 (4.3)	5.7 (8.1)	6.7 (11.8)	0.4	1.8	3.4
Spatial	3.7 (5.1)	3.6 (6.7)	3.2 (6.2)	5.3 (7.4)	3.9 (6.3)	5.8 (6.1)	1.5	0.3	2.5
Alerting	0.4	−0.8	1.9	1.9	0.0	−0.3			
Orienting	0.3	0.3	0.1	−0.8	1.8	0.9			

Note: Standard deviations are in parentheses.

excluded from the RT analysis and ER analysis. Outliers with RTs shorter than 200 ms or longer than 2.5 SDs above the participant's mean (second-language learners = 7.1%, *SD* = 6.6; bilinguals = 9.7%, *SD* = 7.7; trilinguals = 8.7%, *SD* = 6.3) were also excluded from the RT analysis. The RT and error data were analyzed by means of a 4 (Cue Type: no cue, double cue, center cue, or spatial cue) × 2 (Flanker Type: congruent or incongruent) × 3 (Language Group: second-language learners, bilinguals, or trilinguals) ANOVA, treating cue type and flanker type as within-participant variables and language group as a between-participant variable. These analyses are reported under the subheading "General analyses" below. In subsequent "Attentional networks" analyses (see, e.g., Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011), the three effects measured by the attentional networks task were compared separately. The *alerting effect* was calculated by subtracting the double cue type from the no-cue type, the *orienting effect* was indexed by the difference between the center cue type and the spatial cue type, and the *conflict effect* was indexed by the difference between the incongruent and congruent flanker types. The resulting means and SDs are presented in Table 3. Fig. 1 displays the RTs for the two types of flankers, whereas Fig. 2 displays the RTs for the three types of effect by participant groups.

General analyses

In the RT analysis, the main effects of cue type, $F(3,159) = 47.49$, $MSE = 3868$, $p < .001$, $\eta_p^2 = .47$, and flanker type, $F(1,53) = 32.90$, $MSE = 4521$, $p < .001$, $\eta_p^2 = .47$, were significant, but not the main effect of language group, $F(2,53) < 1$. The interactions between language group and cue type, $F(6,159) = 1.67$, $MSE = 3868$, $p = .066$, $\eta_p^2 = .06$, and between language group and flanker type, $F(2,53) = 1.93$, $MSE = 4521$, $p = .078$, $\eta_p^2 = .07$, were marginally significant. The other interactions were not significant ($p > .10$). In the error analysis, only the main effect of cue type, $F(3,159) = 6.13$, $MSE = 24$, $p < .001$, $\eta_p^2 = .10$, was significant (language group and flanker type, *F*s < 1). There were no significant interactions (all *p*s > .10). Thus, the absence of a main effect of language group indicates that overall performance of the three groups of children (as measured by RTs and ERs) did not differ. In the following analyses, we tested specific predictions of differences among the three groups of children in the three attentional networks.

Attentional networks

In these analyses, the three effects of the attentional networks (as indexed by the alerting effect, the orienting effect, and the conflict effect) are assessed independently in relationship to language group (second-language learners, bilinguals, or trilinguals). Interactions between attentional networks effects and the variable language group are used as an index of the effect of bilingualism/trilingualism.

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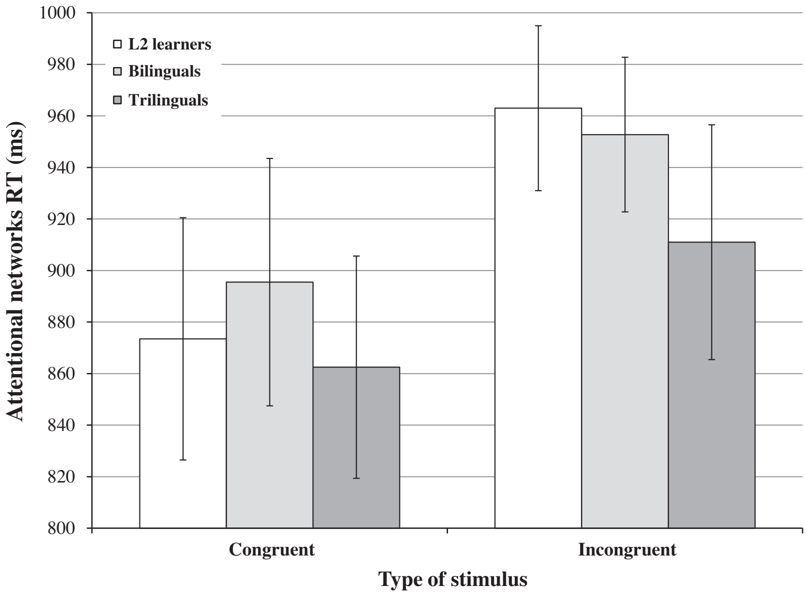

Fig. 1. Mean RTs for congruent and incongruent stimuli in the ANT by language groups for Experiment 2. Error bars represent standard errors.

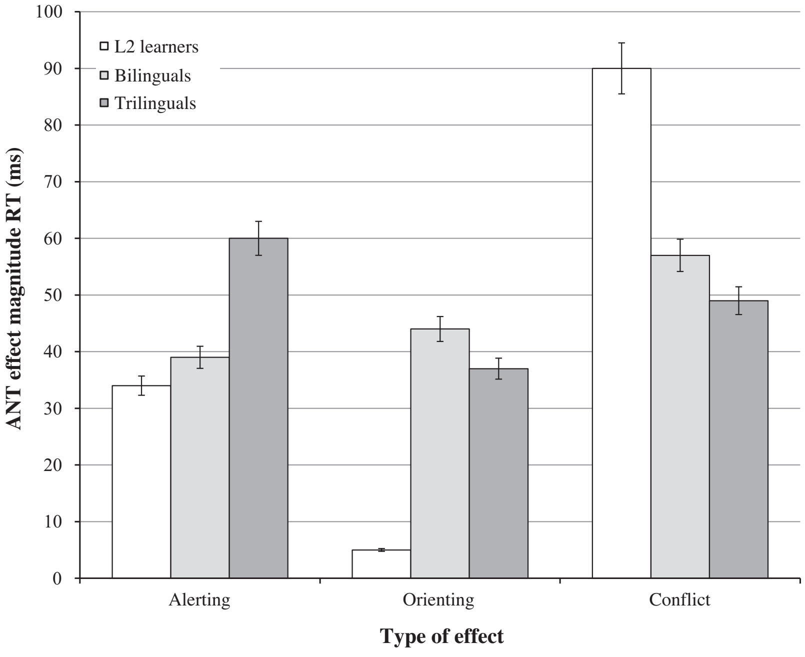

Fig. 2. Effect magnitudes (RTs) in the ANT of the three language groups for Experiment 2. Error bars represent standard errors.

Alerting network. The alerting effect (double cue vs. no-cue trials) was significant in the RT analysis, $F(1,53) = 20.21$, $MSE = 2694$, $p < .001$, $\eta_p^2 = .28$, but the effect of language group and the interaction between language group and alerting effect were not ($Fs < 1$). In the ER analysis, no significant effects were observed (all $Fs > 1$).

Orienting network. The orienting effect (center cue type vs. spatial cue trials) in the RT analysis was significant, $F(1,53) = 10.96$, $MSE = 2116$, $p = .001$, $\eta_p^2 = .17$, but the effect of language group was not ($F < 1$). The interaction between language group and orienting effect was marginally significant, $F(2,53) = 1.97$, $MSE = 2116$, $p = .075$, $\eta_p^2 = .07$. No significant effects were observed in the error analysis (all $Fs > 1$).

Executive network. The conflict effect (incongruent vs. congruent trials) yielded a significant effect, $F(1,53) = 119.89$, $MSE = 991$, $p < .001$, $\eta_p^2 = .69$, but the effect of language group was not significant ($F < 1$). The interaction between language group and conflict effect was significant, $F(2,53) = 4.37$, $MSE = 991$, $p = .009$, $\eta_p^2 = .14$. For the error rates, there was also a significant conflict effect, $F(1,53) = 13.17$, $MSE = 8$, $p < .001$, $\eta_p^2 = .20$, but the main effect of language group and the interaction between language group and conflict effect did not reach significance (all $Fs < 1$).

The attentional network analyses yielded interactions between language group and conflict in the orienting and executive networks in the RT analysis but not in the ER analysis. To further examine the differences in the orienting and executive networks, separate analyses to compare the groups of children (i.e., second-language learners vs. bilinguals, second-language learners vs. trilinguals, and bilinguals vs. trilinguals) were conducted on the RT data.

Second-language learners versus bilinguals. Bilinguals displayed a significantly greater orienting effect (44 ms) than second-language learners (5 ms), $F(1,36) = 3.17$, $MSE = 4634$, $p = .042$, $\eta_p^2 = .08$, indicating a greater benefit induced by the orienting cue for bilinguals. In the resolution of conflict, second-language learners were less efficient (90 ms) than bilinguals (57 ms), $F(1,36) = 4.57$, $MSE = 2115$, $p = .019$, $\eta_p^2 = .11$. The two groups did not differ in overall reaction times to either orienting or conflict trials ($Fs < 1$), showing no global RT advantage for bilinguals over second-language learners.

Second-language learners versus trilinguals. For orienting, trilinguals displayed a marginally significantly greater orienting effect (37 ms) than second-language learners (5 ms), $F(1,35) = 2.37$, $MSE = 4059$, $p = .067$, $\eta_p^2 = .06$. For conflict resolution, trilinguals showed significantly less conflict (49 ms) than second-language learners (90 ms), $F(1,35) = 7.93$, $MSE = 1961$, $p = .004$, $\eta_p^2 = .19$. No global RT difference was found for either network ($Fs < 1$).

Bilinguals versus trilinguals. Bilinguals and trilinguals displayed similar orienting and conflict resolution effects (orienting: 44 vs. 37 ms; conflict: 57 vs. 49 ms), $Fs(1,35) < 1.00$, $p > .30$. No global RT difference was found for either network ($Fs < 1$).

The attentional networks analyses indicated that all three groups of children showed alerting, orienting, and conflict effects, only two of which differed between groups: the orienting and conflict effects. The subsequent comparative analyses on the orienting effect yielded a bilingual and trilingual advantage over second-language learners in benefiting from the orienting cue, whereas the conflict effect indicated that bilinguals and trilinguals experienced less interference than second-language learners from incongruent flankers. Finally, no global RT advantage, indicative of enhanced task monitoring, was found for any of the groups.

General discussion

Multilingual speakers who regularly and repeatedly use more than one language need to display one trait that monolingual speakers do not: the control over which language to choose depending on interlocutor and/or speaking context while avoiding interference from the language not in use. The current study explored whether the necessity for multilingual children to regularly activate attentional control mechanisms during speech production has any effect on the efficiency of these children's general attentional system. For this purpose, we ran two experimental tasks, the Simon task

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and the Attentional Networks Task, with various groups of children with differing language backgrounds. We were particularly interested in whether the groups' performances would inform us about their capacity to resolve conflict, to monitor tasks, and to shift attention—capacities connected to the executive control network.

As expected, all groups of children responded faster in congruent conditions than in incongruent conditions both in the Simon task and in the ANT, displaying results that are in line with previous studies (e.g., Bialystok et al., 2004; Carlson & Meltzoff, 2008; Rueda, Fan, et al., 2004). Furthermore, in the ANT, participants' responses were faster when a warning cue was presented prior to the target stimuli (alerting network), and the location of the target stimuli was indicated by a spatial cue beforehand (orienting network).

There were, however, critical quantitative differences between the groups. As predicted, the bilinguals and trilinguals displayed less interference in the incongruent Simon task condition than the monolinguals, indicating that the language control continuously exercised by the bilinguals and trilinguals has a more general effect on attentional control mechanisms (see Figs. 1 and 2). Although numerically there was an advantage for the L2 learners over the monolinguals, and a disadvantage for the L2 learners over the bilinguals and trilinguals, this was not borne out statistically. This suggests that the L2 learners' enhanced attentional control was emerging but had not yet reached performance levels of the bilinguals and trilinguals. Compared with the bilinguals and trilinguals, the L2 learners had had limited L2 immersion experience and less experience in controlling their two languages. In addition, the L2 learners may still have been in a stage of language acquisition in which their L2 speech production output, and thereby the need for language control, was limited. As reported by the English-speaking teachers in the bilingual schools in which data collection for this study took place, the L2 learner children were able to understand their interlocutors' English but prominently chose their L1 German to produce language (see also Paradis & Nicoladis, 2007, for language dominance influencing language choice in bilingual preschoolers).

The ANT showed significant advantages for the bilingual and trilingual children over the second-language learners in benefiting from the orienting cue and in showing less interference in resolving conflict. At the same time, no global RT advantage was found for any of the groups, so the groups do not differ in task monitoring. As such, the observation made in the ANT that bilinguals and trilinguals displayed enhanced conflict resolution over L2 learners is in line with the Simon task results. Moreover, the fact that bilinguals and trilinguals did not differ significantly in their performances in either the Simon task or the ANT suggests that dealing with and negotiating among three languages, instead of between two languages, on a daily basis does not suffice to enhance attentional control even more.

Finally, in the current study, the ANT yielded no group differences in the alerting network, which is contrary to the results reported by Costa et al. (2008) with adult Catalan–Spanish bilinguals but is in line with findings by Costa et al. (2009) in the same population. Furthermore, group differences in the ANT were found in the orienting network, running counter to results obtained with adult bilinguals in Hernández, Costa, Fuentes, Vivas, and Sebastián-Gallés (2010). It is possible that whereas all children in the current study profited from the spatial cue indicating the correct location of the following target, the bilingual and trilingual children were able to exploit the orienting cue to a significantly greater extent than the second-language learners. In line with Tao et al. (2011), we explain this effect difference as stemming from bilingual and trilingual children displaying an enhanced ability to exploit and use location stimuli more efficiently. Furthermore, the observation that the children in our study showed significant differences in this network can be viewed as a developmental phenomenon. It could be evidence that the enhanced language control that these individuals need to administer within their still developing language systems in order to choose the target language for communication boosts their orienting performance in this task.

The fact that the bilinguals and trilinguals in the current study suffered less interference from incongruent trials than the monolinguals and L2 learners suggests that the general executive control network is differentially developed in the bilingual and trilingual children and can be explained in two ways, namely that (a) bilingualism helps in monitoring, shifting attention, and resolving conflict when responding to specific stimuli or (b) bilingualism attenuates the impact of irrelevant information for the task at hand. These results partially replicate and, critically, expand previous research showing that multilingualism affects the performance of children and adults in nonlinguistic tasks that require

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attentional control. Furthermore, they provide novel evidence for similar performance of bilinguals and trilinguals in such tasks, indicating that dealing with more than two languages does not lead to more strongly enhanced attentional control in trilinguals compared with bilinguals. As such, whether dealing with more than one language or more than two languages seems to have no differential effect. Moreover, the data of the L2 learners showed that being subjected to a second language at an early age is insufficient to fully accrue the cognitive control advantages found in bilinguals. Evidently, a specific threshold in exposure and usage needs to be reached before such advantages as outlined above take full effect.

A further prediction made in the Introduction of this study was that bilinguals and trilinguals would also outperform the other speaker groups in overall reaction times. This was not borne out in either experiment in that bilinguals and trilinguals were not significantly faster than L2 learners and monolinguals in the Simon task, and bilinguals and trilinguals were not significantly faster than L2 learners in the ANT, in both congruent and incongruent trials. This observation contrasts the findings of Bialystok et al. (2004, 2005, 2006), who found overall faster RTs for bilinguals over monolinguals and interpreted this as an enhanced bilingual monitoring capacity connected to the more efficient executive control mechanism caused by continuous bilingual language control. In other words, the possible switch between incongruent and congruent trials engages a participant's cognitive resources in monitoring the task, even in trials without conflict resolution. Thus, participants with more efficient executive control mechanisms will respond faster in both kinds of trials because they will be less affected by the increased attentional demands of the task. As pointed out above, the groups in our study did not differ in overall reaction times. Costa et al. (2008) noted that although the two mechanisms (monitoring and conflict resolution processes) are related to the same network, they are affected relatively independently by bilingualism. That is, conflict resolution processes becoming more efficient does not necessarily mean that monitoring processes also improve. Thus, the interaction between these two components of the executive control network requires further exploration in light of the observations made in this study compared with the mixed results in earlier studies.

Future research could focus specifically on, for example, exploring the time course of possible enhancements in executive control in young L2 learners, assessing how much and how long L2 learners need to be immersed for significant effects to emerge, and determining whether bilingual and trilingual populations show within-group differences in language control behavior that could prove to be helpful in controlling participant group variability. Addressing these issues should be beneficial in informing research in the domain of bilingualism and multilingualism.

In conclusion, the results presented in this article add to the growing body of evidence showing the benefits of bilingualism for the executive control network's efficiency. The tasks used in our experiments tapped into the executive control network components, and the results suggest a beneficial effect for one subcomponent in particular, namely conflict resolution. Critically, the current study also showed that cognitive control benefits for second-language learners with limited input in their L2 (as compared with bilinguals and trilinguals) were not (yet) accrued. Moreover, dealing with three languages rather than two languages, which potentially increases the need for language control to navigate and use these languages accordingly, did not materialize in larger cognitive control advantages in trilingual children relative to bilingual children.

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