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Cognitive advantages of immersion education after 1 year: Effects of amount of exposure

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ABSTRACT

Previous studies with bilingual children have shown that the nature of their second-language instruction has an effect on the development of their cognitive abilities. The aim of this study was to determine whether children who acquire a second language in two different immersion programs for a period of 1 year show advantages in executive functions and to examine how the amount of *daily exposure* affects executive functions. A group of Serbian-speaking second-grade children exposed to the second language for about 5 h each day (high exposure group, HEG) and a low-exposure group (LEG) exposed to the second language for about 1.5 h each day were compared with an age-matched control group (CG) of monolingual peers on working memory, inhibition, and shifting. Significant group differences were found for working memory, with the HEG performing better than the CG and LEG even after controlling for individual differences in terms of age and intelligence. The three groups did not differ in terms of inhibition and overall shifting abilities, although the control group had a marginally significant advantage on one of the two shifting tasks. Our findings extend previous research by demonstrating that the amount of daily exposure is a significant factor affecting executive functions in early immersion programs for second-language acquisition. In addition, they show that early intensive second-language acquisition can be advantageous for performance on tasks that require a higher level of executive control.

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Introduction

A large body of research has shown that bilingualism has a positive effect on cognitive development (Bialystok, 2011; Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008; Poarch & Van Hell, 2012; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011). The positive impact of bilingualism has been observed in a variety of tasks that require cognitive control components such as selective attention (Bialystok, 2001), cognitive flexibility (Poulin-Dubois et al., 2011), and engagement of working memory (WM) (Morales, Calvo, & Bialystok, 2013). All of these cognitive control components fall under the umbrella term *executive functions* (EFs), which encompass three core abilities: *inhibition*, defined as either inhibition of prepotent responses or incoming interference; *shifting*, which comprises mental set shifting or switching; and *working memory*, which involves information updating and monitoring (Miyake et al., 2000).

How could one explain this positive effect of bilingualism on EFs? There is now overwhelming evidence that when we speak both languages are active to some degree, even in contexts that clearly support only one of the languages (Francis, 1999; Kroll, Bobb, & Wodniecka, 2006; Marian, Spivey, & Hirsch, 2003; Rodriguez-Fornells, Rotte, Heinze, Nosselt, & Munte, 2002; Thierry & Wu, 2007). These studies suggest that there is a high probability of interference from the nonrelevant language when the other one is in use as the two languages potentially compete for cognitive resources. In order not to erroneously use the unintended language or lose fluency in either of the languages, bilinguals must acquire a way to control or regulate that competition (Bialystok, 2001; Kroll, Dussias, Bice, & Perrotti, 2015). In other words, bilingual individuals are placed in a situation where executive control is required; while speaking, the speaker plans the content of his or her utterance taking into consideration the current topic and context (which requires WM), selects relevant linguistic structures in one language (which requires inhibiting the competing structure of another language), monitors the progress of the interaction within a certain topic and removes from the storage system all content that was used but is no longer relevant for the conversation (which also requires WM), and potentially switches between languages (which requires shifting).

To date, studies with bilingual children have primarily focused on one specific component—inhibition. However, the results from these studies have been controversial. Studies using the Stroop and Simon tasks have found significantly better performance in bilinguals compared with their monolingual counterparts (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Hernández, Costa, & Humphreys, 2012). Martin-Rhee and Bialystok (2008), however, reported that bilinguals outperform monolinguals on a variety of tasks that require control over attention to competing cues (interference suppression), but not on tasks requiring inhibition of a habitual or prepotent response. Results obtained from recent studies with large sample sizes have further challenged the earlier research findings by showing no bilingual advantage in inhibitory control in either children or adults (Antón et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2014; see Valian, 2015, for a review of the relevant issues).

Recently, a shift has been made from viewing inhibition as the only cognitive control component relevant for bilingual language use to taking a more global overview of all EF components. Some of these studies have provided supporting evidence for bilingual advantages in shifting ability (Bialystok, 2010; Okanda, Moriguchi, & Itakura, 2010; Prior & MacWhinney, 2010), although these findings have not been replicated across studies (Paap & Greenberg, 2013). A carefully conducted study by Xie (2014) suggested a more complex picture by showing that language use and language-switching experience, but not proficiency in the second language, significantly contribute to performance on tasks tapping shifting ability.

The controversy regarding bilingual advantages also extends to the third component of EFs, namely WM (Engel de Abreu, 2011; Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012). According to Baddeley (1998), WM is a multicomponent, capacity-limited system that handles current demands for temporarily storing and managing the information required to carry out complex cognitive tasks. It is well established that WM performance is strongly related to language acquisition and processing (Archibald & Gathercole, 2006; Majerus, Poncelet, Greffe, & van der Linden, 2006). The central executive component is a flexible system responsible for the control and regulation of cognitive processes (Baddeley, 1998) that plays an important role in oral and written language processing (Cain, Oakhill, & Bryant, 2004; Daneman & Carpenter, 1980; Gathercole, Alloway, Willis, & Adams, 2006; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000). The phonological loop (short-term verbal memory), the most important domain-specific component of WM for language processing, includes a capacity-limited, phonological, short-term storage buffer and an articulatory control process that refreshes and maintains speech material in storage for a brief period (Montgomery, 2003). The phonological loop's main role in language acquisition and development is to temporarily store verbal input so that it can be used for further processing (Baddeley, Gathercole, & Papagno, 1998). In addition, short-term verbal memory performance is strongly related to language learning in both native and foreign languages (Engel de Abreu, 2009; Engel de Abreu, 2011; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Service, Hitch, Adams, & Martin, 1999; Majerus et al., 2006; Masoura & Gathercole, 2005).

There are reasonable grounds to believe that WM could be associated with bilingualism. Coping with the demands of controlling two languages might affect WM performance through its impact on the central executive component regardless of the modality (visuospatial or verbal). In other words, bilinguals may exhibit more efficient WM abilities than monolinguals because the bilingual environment provides EF training as a result of the continuous need to monitor which language to use in each communicative interaction and to store and update this information. However, further research is needed to establish whether or not bilingualism has an effect on WM abilities (Hernández et al., 2012). For example, Morales et al. (2013) found WM advantages in 5- and 7-year-old bilingual children in the Frog Matrices task. In this task, children needed to remember the locations of a frog in a pond. The bilingual advantage was especially prominent in the executive-loaded sequential condition that required recalling both the locations of the frog and the order of the locations. Similarly, Blom, Küntay, Messer, Verhagen, and Leseman (2014) reported a bilingual advantage for visuospatial and verbal WM in 5- and 6-year-old Turkish–Dutch-speaking children. Visuospatial WM was assessed using the dot matrix task from the Automated Working Memory Assessment (AWMA; Alloway, 2007). In this task, children were shown a series of screens on which a red dot appears in a matrix and were asked to recall the coordinates of the dots. Blom et al. (2014) also assessed verbal WM using the forward digit recall and backward digit recall tasks. They found a bilingual advantage for the dot matrix task and the backward digit recall task; the bilingual advantage was also stronger for the backward digit recall task, which requires both storage and processing, than for the dot matrix task, which is considered more of a visuospatial storage task. In addition, Bialystok and Feng (2009) reported that bilinguals outperformed monolinguals on memory recall tasks involving proactive interference—the situation where retrieval of recent material is impaired by prior exposure to similar items. In contrast, Engel de Abreu (2011) found no bilingual advantage for visuospatial WM, although her tasks and population of bilingual children were very comparable to those in Morales et al. (2013) study.

Research on factors responsible for the relationship between bilingualism and EFs has demonstrated that the level of bilingual proficiency should also be accounted for; a more balanced level of proficiency in the two languages, together with more balanced language use, leads to better executive control skills, at least in bilingual adults (Luo, Luk, & Bialystok, 2010; Yow & Li, 2015).

Second-language education and executive control

The majority of studies examining EFs in bilingual children have compared monolingual children with children who have had a lifetime's experience with a second language (Bialystok, Peets, & Moreno, 2014; see Blom et al., 2014, for research on immigrant children). To date, only a handful of studies have investigated the interplay between EFs and dual language development in bilingual children attending different second-language education programs. Poarch and Van Hell (2012) studied EFs in monolingual, bilingual, and trilingual children as well as in children in the process of learning a second language. According to their results, second-language learning children performed in between their monolingual and bilingual/trilingual peers. This finding suggested that enhanced executive control was emerging in the second-language learners but had not yet reached levels similar to those of the bilingual and trilingual children. In a recent study by Pelham and Abrams (2014), however, early bilinguals who became fluent in the second language before age 7 years and late bilinguals who became fluent in the second language from age 13 years onward exhibited similar overall EF benefits, with both groups surpassing their monolingual peers in this respect. These results suggest that second-language experience brings benefits to cognitive control in children despite different ages of second-language onset and, presumably, length of exposure. In another study, Luk, de Sa, and Bialystok (2011) investigated the relationship between age of second-language onset and EFs in two groups of early and late bilinguals and found that the early bilinguals outperformed both monolinguals and late bilinguals, with the latter two groups performing at a similar level. Apart from the obvious effect of age of second-language onset, the authors interpreted these results as suggestive that "more experience in being actively bilingual is associated with greater advantages in cognitive control and higher language proficiency" (p. 588).

However, as Bialystok et al. (2014) pointed out, what is less clearly understood is exactly when and how these advantageous effects surface in the context of emerging bilingualism. Studies comparing children in immersive education programs with children in monolingual education, although not fully comparable in terms of participant group selection (different ages and spoken languages) or in terms of the experimental tasks used, have provided mixed results regarding the effect of length of exposure on EFs (Bialystok et al., 2014; Carlson & Meltzoff, 2008; Nicolay & Poncelet, 2013). Bialystok and Barac (2012) and Bialystok et al. (2014) showed that executive control performance improves as a function of increased language experience in an immersion program in 7- to 11-year-old children. Nicolay and Poncelet (2013) found that 8-year-old children enrolled in an immersion program for 3 years significantly outperformed their monolingual peers on tasks assessing alerting, auditory selective attention, divided attention, and mental flexibility, suggesting that 3 years of second-language immersion is sufficient to produce some of the executive benefits associated with early bilingualism. In their study of preschool children who had attended an immersion program for 6 months, Carlson and Meltzoff (2008) found that these children did not differ from their monolingual peers on inhibition, shifting, and WM tasks. A possible interpretation of these findings could be that the level of language proficiency is the key variable through which language experience influences EFs. Indeed, a positive relationship has been demonstrated between the level of language proficiency and performance on tasks tapping EFs (Iluz-Cohen & Armon-Lotem, 2013).

The current study

Bearing in mind the studies mentioned above showing that EFs improved with increased language experience in a bilingual education program after 3 years (Nicolay & Poncelet, 2013), but not after 6 months (Carlson & Meltzoff, 2008), we proposed two hypotheses. First, attending a second-language immersion program for a period of 1 year will bring about better EF abilities. Second, the *amount of exposure* will determine the size of the effect on EFs. To test these hypotheses, we selected second-grade Serbian-speaking children from two different immersion programs: a high-exposure group (HEG) of children who attended a program of second-language acquisition for about 5 h each day and a low-exposure group (LEG) of children who were exposed to the second language for about 1.5 h each day. The two groups were compared on WM, inhibition, and shifting with an age-matched control group (CG) of children attending mainstream monolingual schools in Belgrade, Serbia. Our hypotheses predicted that both immersion groups would outperform the monolingual group on EF tasks but that the differences would be larger for the HEG.

Method

Participants

A total of 58 typically developing, monolingual Serbian-speaking children were included in the sample: 19 in the HEG, 17 in the LEG, and 22 in the CG. All children were Serbian nationals raised monolingually, and their mean age was 7 years 11 months (*SD* = 7 months). The children in the HEG were attending international schools in Belgrade. These are immersion schools where all subjects are taught in a second language (either English or German) for about 5 h each working day. At the time of testing, children in the HEG had attended immersive education for at least 1 year. The LEG consisted of children immersed in an intensive second-language acquisition program within an experimental school with a gradually increasing number of second-language lessons (French). During the first year, this program includes more than 6 h of second-language classes each week, which roughly corresponds to 1 h and 20 min (total 80 min) each working day. The children in the sample had been enrolled in this program for more than 1 year at the time of testing. The children in the CG attended standard monolingual Serbian-speaking primary schools in Belgrade. Schooling in Serbia starts at the age of 7 years, and all children were attending the second grade at the time of testing. The groups were also comparable in terms of socioeconomic background assessed by parental education. The school principals provided information on the percentage of parents who had completed high school (12 years of education) or university education (16 years of education in total).[1] In total, 16 mothers and 18 fathers in the HEG, 12 mothers and 15 fathers in LEG, and 19 mothers and 19 fathers in the CG had completed 16 years of education. Yates' corrected chi-square indicated that there were no significant group differences in either maternal education, $\chi^2 = 0.76$, $p = .68$, or paternal education, $\chi^2 = 0.19$, $p = .91$.

To be included in the study, participants also needed to meet the following criteria: intellectual abilities between the 25th and 90th percentiles, normal hearing, normal or corrected-to-normal vision, and no history of neurological disorders, behavioral problems, or any other psychopathological issues. The three groups did not differ in their average age or intellectual abilities (Table 1).

Materials

A comprehensive battery of EF tests was administered to all participants along with a test of fluid intelligence. All EF tasks were constructed and administered using E-Prime software (Schneider, Eschmann, & Zuccolotto, 2002) and were presented to participants on Acer Iconia Tab computers. The intelligence test was administered in a paper-and-pencil form.

Fluid intelligence

Children were administered the Raven's Colored Progressive Matrices test (Raven, Court, and Raven, 1986), in which they are required to complete a geometrical figure by choosing a missing piece from a list of six possible choices. The total number of items is 36. Every answer is scored as 1 when correct and 0 when incorrect, with a total maximum score of 36. The scores were age corrected.

Working memory

Children completed two complex span tasks. Bearing in mind that WM tasks differ in modality and complexity, for the purposes of our study, two complex WM tasks were selected: the counting recall task and the backward digit recall task. Both tasks are verbal WM tasks; however, they were selected mainly because of their frequency of use and ease of administration. Furthermore, because the phonological loop is the most engaged in language processing, we would expect larger effects on verbal memory than on nonverbal memory. Both measures require participants to simultaneously process and store information. The number of items to be remembered increases progressively over successive blocks containing four trials each. Test administration stops if children fail to correctly recall three trials in one block. Both span score (the longest number of items participants can repeat) and task score (the number of correct responses) are sometimes used as indicators of WM capacity. To get the most information from the data, we chose to use both measures as dependent variables.

Counting recall task. The counting recall task was taken from the Serbian adaptation of the AWMA[2] (Alloway, 2007). Participants are presented with a varying number (four to seven) of red dots and blue

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[1] This information was provided for each child individually, but in an anonymized way, so that it was impossible to match it to other participants' scores. Therefore, even though socioeconomic status could not be included in the analyses as a covariate, we were still able to individually match participants on parental education.

[2] The Automated Working Memory Assessment. Copyright © (2007) by Pearson Assessment. Serbian Translation Copyright © (2013) by Pearson Assessment. Translated and reproduced with permission. All rights reserved.

Table 1
Subsample mean age and intelligence.

	CG		LEG		HEG				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2
Age in months	94.6	6.9	98.2	2.2	93	8.7	2.87	.07	.10
Raven's CPM	26.7	2.5	27.7	3.5	28.3	4.5	0.99	.38	.04

Note. CG, control group; LEG, low-exposure group; HEG, high-exposure group; CPM, Colored Progressive Matrices (age-corrected scores).

triangles on the screen. Their task is to count the number of red dots and memorize it. The number of consecutive images shown before the recall phase varies from one to seven.

Backward digit span task. The backward digit span task was taken from Huizinga, Dolan, and Van der Molen (2006). In this task, participants hear a number sequence and are required to repeat it in reverse order. The sequences get progressively longer, ranging from two to eight numbers.

Inhibition

Nonverbal Stroop task. The nonverbal Stroop task was taken from Lukács, Ladányi, Fazekas, and Kemény (2016) and uses arrows pointing upward, downward, left, and right as stimuli.[3] The task has three blocks with 60 trials each. In the first (control) block the arrows are presented in the middle of the screen, in the second (congruent) block the arrows are presented in their corresponding positions on the screen (with the arrow pointing left on the left side of the screen, etc.), and in the third (incongruent) block the arrows are presented on the opposite side of the screen (with the arrow pointing left on the right side of the screen, etc.). Participants' task is to determine the arrow's orientation regardless of its on-screen position, responding by pressing a button. The difference in reaction times (RTs) for congruent and incongruent trials represents the inhibition cost.

Shifting

Participants were also administered two shifting tasks, each containing three blocks. In the first block, children are required to respond to stimuli presented in the upper half of the screen by paying attention to one of the stimulus dimensions. In the second block, the same stimuli are presented in the lower half of the screen, and the dimension that needs to be responded to is different. Finally, in the third (critical) block, children need to alternate between the two dimensions, depending on the on-screen position of the stimulus (above or below a horizontal line dividing the screen). Cues directing participants to the relevant dimension are presented simultaneously with the stimuli on all trials in all blocks. The first two blocks contain 32 trials each, and the third block contains 64 trials. The numbers of shifting and nonshifting sequences in the third block are balanced. The difference in RTs for the first two (nonshifting) blocks and the third (shifting) block represents the general shifting cost. Local shifting cost is reflected by the difference in average RTs for shifting and nonshifting trials in the third block.

Local–global task. The local–global task was adapted from Huizinga et al. (2006) and uses four complex figures shown in Fig. 1. In the first block participants' task is to respond to the shape of the larger figure (determining whether it is a square or a rectangle), in the second block their task is to respond

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[3] Initially, two tasks were used to assess inhibition. Unfortunately, due to a programming error causing participant responses not to be recorded, the other inhibition task (stop signal task) needed to be excluded from further analyses. The main drawback of this lack of data is that it makes the generalization of any registered effects less convincing than if two tasks had been used. In addition, some previous studies (Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008) have shown that bilingual children do not differ from monolingual children on measures of response inhibition but do differ on measures of interference inhibition, although this finding is not always replicated (Bialystok, Barac, Blaye, & Poulin-Dubois, 2010; Verhagen, Mulder, & Leseman, 2017). For that reason, although it would have made our design more balanced to have included this task, we do not think that it significantly compromises the importance of our findings.

Fig. 1. Complex figures used as stimuli in the local–global task.

to the shape of the smaller figures, and in the third (critical) block participants must shift between the two response types.

Color–shape task. In the color–shape task, developed for this research, participants are presented with the following four figures: blue/red triangles/circles. In the first block participants are required to respond to the shape of the stimulus, in the second block they need to respond to its color, and in the third block they need to alternate between the two types of decisions.

Procedure

Institutional approval for human investigation was received before participants were tested. All parents gave informed written consent for their children to take part in the research, and the schools gave permission for the testing to be conducted on their premises. The tasks were administered individually to all participants in quiet rooms in their schools. The tasks were administered in two sessions lasting up to 30 min each, including an initial period of establishing rapport with children through play. The tasks were administered in a fixed predefined order: counting recall task, color–shape task, break, nonverbal Stroop task, backward digit span task, and local–global task. Raven's Colored Progressive Matrices were always administered first in order to exclude children who perform below the 25th percentile or above the 90th percentile; no children needed to be excluded on the basis of this criterion. The break between sessions was no longer than 3 days, and short breaks were also taken between each pair of consecutive tasks to ensure that children were rested and motivated to participate in the research.

Data processing

Response accuracy was recorded for all tasks, and for shifting and inhibition tasks RTs were recorded as well. All RTs shorter than 200 ms and all RTs for incorrect trials were excluded from the analysis. Furthermore, the data were trimmed both between and within participants, so that values more than ±3 standard deviations away from the (average and each participant's) mean RT were replaced by the ±3 standard deviation values. On both shifting tasks, the general shifting costs, used by Miyake et al. (2000), were calculated as differential RTs by subtracting the average RT for the third block from the average RTs for the first two blocks taken together. Local shifting costs were calculated by subtracting the average RTs for the shift trials in the third block from the average RTs for the nonshift trials within the same block. For both general and local shifting costs, values are expressed as negative numbers, such that higher values correspond to better shifting ability. In the nonverbal Stroop task, the inhibition cost was calculated as the difference between average RTs for congruent and incongruent stimuli. Higher scores indicate better inhibition.

Results

Table 2 shows the groups' performance on EF tasks and the significance of group differences tested by a series of analyses of covariance (ANCOVAs) with age and intelligence as covariates. ANCOVAs were chosen over a multivariate analysis of covariance (MANCOVA) because some of the dependent variables correlated highly among themselves (e.g., backward digit span and score correlate $r = .92$, $p < .01$), making the data unsuitable for MANCOVA. Age was not a significant covariate for any of the tasks, whereas intelligence was significantly related to performance on the local–global task.

Table 2
Results of ANCOVAs for executive function task scores with group means and standard deviations.

	CG		LEG		HEG		Age			Intelligence			Group		
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
Counting recall score	12.3	2.9	12.7	2.8	14.7	2.7	0.67	.42	.01	3.61	.06	.06	3.81	.03	.13
Counting recall span	4.0	0.9	4.4	0.9	4.7	0.9	0.49	.49	.01	1.88	.18	.03	3.38	.04	.11
Backward digit score	7.3	2.3	8.4	2.1	9.4	2.8	3.01	.09	.05	0.06	.81	.00	4.18	.02	.14
Backward digit span	3.1	0.8	3.4	0.6	3.7	0.7	0.45	.51	.01	0.11	.75	.00	4.03	.02	.13
Nonverbal Stroop differential Reaction time (ms)	−206.0	33.1	−308.0	38.8	−291.6	35.6	0.49	.49	.01	0.17	.68	.00	2.14	.13	.08
Nonverbal Stroop overall reaction time (ms)	797.5	54.9	881.6	62.4	966.3	59.1	2.24	.14	.04	3.28	.08	.06	3.33	.04	.11
Color–shape general cost (ms)	−296.7	164.9	−354.8	274	−335.2	167.4	2.19	.15	.04	0.01	.91	.00	0.29	.75	.01
Color–shape local cost (ms)	−98.0	127.8	−169.8	97.6	−192.9	134.0	1.23	.27	.02	0.33	.57	.01	3.04	.06	.11
Local–global general cost (ms)	−174.1	178.5	−201.4	164.5	−190.3	144.8	0.10	.75	.00	6.07	.02	.10	0.03	.97	.01
Local–global local cost (ms)	−103.7	158.8	−115.1	93.7	−168.9	105.6	3.25	.08	.06	5.65	.02	.10	0.52	.60	.02

Note. CG, control group; LEG, low-exposure group; HEG, high-exposure group.

The differences between the groups emerged on both WM tasks. Least significant difference (LSD) pairwise group comparisons revealed that children in the HEG significantly outperformed the control group, $D = 2.22$, $p < .05$, $D = 0.72$, $p < .05$, $D = 2.21$, $p < .01$, and $D = 0.69$, $p < .01$, for counting recall score, counting recall span, backward digit score, and backward digit span, respectively. By contrast, the nonintensive exposure group's scores were between the HEG and the LEG scores and did not differ significantly from either the HEG or CG scores.

A marginal main effect of group was found in the local shift cost of the color–shape task. LSD pairwise group comparisons revealed that the CG significantly outperformed the HEG, $D = 95.03$, $p < .05$. The LEG did not differ significantly from the other two groups. However, this result was not replicated on the other shifting task (the local–global task).

On the Stroop task, no group difference was found for the inhibition cost as measured by the differential RTs between the congruent and incongruent conditions (Table 2). Surprisingly, however, a main effect of group emerged for the Stroop task overall RT in that the CG was significantly faster on this task (668 ms for congruent trials and 874 ms for incongruent trials) than the HEG, $D = -210.02$, $p < .05$ (811 ms for congruent trials and 1102 ms for incongruent trials), whereas the LEG did not differ significantly from either group (706 and 1003 ms for congruent and incongruent trials, respectively). Although overall RT for the Stroop task is not a measure of inhibition per se but rather an aspect of cognitive speed, when viewed in combination with the differential RT it can potentially shed additional light on participants' performance on this task. It appears that the Stroop task was comparatively more difficult for the HEG than for the CG; however, this did not lead to differential slowing down on the task, resulting in a lack of difference in inhibition performance.

Discussion

Previous studies investigating the interplay between EF and dual language development of bilingual children attending second-language education programs have shown that the length of second-language exposure plays an important role. Nicolay and Poncelet (2013) reported positive effects of a 3-year immersion program on tasks assessing alerting, auditory selective attention, divided attention, and mental flexibility, thereby suggesting that 3 years of second-language immersion school experience produces some of the EF benefits associated with early bilingualism. On the other hand, Carlson and Meltzoff (2008) demonstrated a bilingual advantage on a wide range of EF measures, but no such evidence was found for a 6-month second-language exposure program, suggesting that 6 months of intensive second-language acquisition is not enough to affect executive control.

To expand our understanding of effects of second-language exposure on EFs, we set up two hypotheses: first, that 1 year is long enough to yield an advantage in EFs for children immersed in a second-language program and, second, that the amount of exposure to the second language contributes to the size of this advantage. In our study, we analyzed three components of EFs as described by Miyake et al. (2000): WM, inhibition, and shifting.

Our first prediction, that 1 year in an immersive second-language program is enough to affect the outcomes of tasks tapping EF in children irrespective of the amount of exposure, was not supported by our data. No significant EF differences were found between the LEG and the CG, suggesting that this length of exposure is not necessarily sufficient to yield an advantage on EF tasks.

However, the data obtained in our study confirmed our second hypothesis by demonstrating an effect of the daily amount of exposure within a second-language immersion program on WM. The HEG outperformed the CG on both complex WM tasks, whereas the LEG performed at a level between the HEG and CG and did not differ significantly from either. This finding cannot be explained by the influence of confounding variables such as environment (children in all three groups came from monolingual homes in similar communities), intellectual abilities (which were comparable across groups), and socioeconomic backgrounds (which were comparable across groups). Under the assumption that the amount of exposure to a second-language immersion program affects EFs, the observed difference between the HEG and the CG suggests that children with a higher amount of exposure to the second language get more practice in WM performance. The advantage in WM ability, thus, may be a consequence of children's continuous monitoring of the vocabulary and syntactic structures of the language in use as well as their continuous storing and updating of this information. Our finding is in line with previous studies showing an advantage for 5- to 7-year-old bilingual children on both verbal and visuospatial WM as compared with monolinguals (Bialystok, 2010; Blom et al., 2014; Morales et al., 2013).

According to our data, about 5 h of daily exposure to a second language for 1 year within an immersion program affects WM performance but not shifting and inhibition. More precisely, in the case of inhibition the results were somewhat unexpected; the groups differed in overall RT on the Stroop task but not on differential RT, which is the primary measure of inhibition. Overall RT could be interpreted as either a consequence of general cognitive speed or an indicator of task difficulty for different groups (Hilchey & Klein, 2011). Thus, our results would imply that the Stroop task may have been more difficult for the HEG than for the LEG and the CG; however, this group did not show weaker inhibition performance than the other two groups.

On the shifting task, we found a control group advantage that approached significance. This result, however, needs to be interpreted with caution for the following reasons. First, the group differences were reaching significance on one shifting task but not on the other, which employed the same methodology. To provide better insight into potential disadvantages of learning a second language on shifting ability, at least in some stages of language acquisition, future studies should employ a larger number of diverse shifting tasks. Second, the sample size of the groups in the current study was relatively small; hence, no strong claims can be made on the basis of these unequivocal results.

Our demonstration of a differential effect of the amount of daily exposure to a second language on the development of EFs—that is, the presence of an effect on WM but not on other EF components, in this case shifting and inhibition—should inform theoretical models of EFs by distinguishing among different component processes and by highlighting their importance for the activity that is controlled. Huizinga et al. (2006) suggested that various EF components may develop asynchronously. It is likely that during the initial period of intensive second-language acquisition, the processes of forming basic vocabulary and syntactic structures in the second language primarily engage WM. This would be similar to the processes described in monolingual acquisition, where WM abilities are strongly related to the rate of language acquisition and the efficiency of processing (Gathercole & Baddeley, 1990; Majerus et al., 2006; Montgomery, 2003). Consequently, WM may be the most important component during the initial period of second-language acquisition. As Bialystok and Barac (2012, p. 72) noted, " [Cognitive] control is sensitive to accumulating experience; executive control tasks rely on domain-general systems that are also recruited in bilingual language processing, but it takes time for these systems to reach sufficient levels to influence non-linguistic domains."

In line with this, Costa, Hernández, Costa-Faidella, and Sebastián-Gallés (2009) argued that the nature of bilingual experience affects the development of different EF components. The authors proposed that in an environment where the two languages are mostly used in different contexts, bilingual speakers might not show advantages in cognitive control mechanisms. In the current study, children attending the high-exposure second-language immersion program for a period of 1 year are in a sociolinguistic environment where the second language is used to a certain extent and in certain contexts at school. In this case, the use of the two languages is confined to clearly separated contexts, and as such the need to inhibit one language or switch between the two languages is rather limited. As a consequence, cognitive control mechanisms, such as inhibition and shifting, might not be engaged to a sufficient degree to reach those levels that would influence nonlinguistic domains.

Our results showed that 1 year of immersion in a second-language learning program is not automatically sufficient to yield an effect on EFs even in the case of WM. The effect seems to be influenced by the *amount of exposure*. According to the results from our study, there is little evidence for a selective advantage of the low-exposure early immersion school program on selected measures of EFs. With age and overall intelligence controlled, after a period of 1 year of second-language instruction, the LEG performed similarly to the CG on tasks assessing WM. The dissociation between the two exposure groups indicates that the amount of exposure needs to be taken into account.

Green and Abutalebi (2013) proposed the *adaptive control hypothesis*, according to which "language control processes themselves adapt to the recurrent demands placed on them by the interactional context" (p. 515). This adaptation may concern the processes' own neural instantiation or their functional relationship to other control processes. On this view, increasing second-language proficiency calls for the speaker to adapt the processes that control interference. Specifically, "interactional cost imposes a demand to adapt the control processes of goal maintenance, conflict monitoring, and interference suppression" (p. 521). This claim is supported by neuroimaging studies demonstrating that bilingualism changes the brain so as to make it more efficient in particular contexts (Della Rosa et al., 2013). Alternatively, it could be that the level of language proficiency is the bridge between the amount of bilingual exposure and EFs—that is, that participants exposed to the intensive program have significantly increased their language proficiency, which in turn produced a benefit on tasks that involve WM ability. From this point of view, both the level of proficiency and the amount of exposure, provided they are balanced in the language environment, lead to better executive control skills (Luo et al., 2010; Yow & Li, 2015).

In line with this, our data suggest that the initial period of intensive second-language acquisition engages verbal WM, and consequently general WM, in a way quite similar to WM engagement during the period of early language acquisition in monolinguals (Gathercole & Baddeley, 1990; Majerus et al., 2006; Montgomery, 2003).

Limitations of the study

Due to practical considerations, namely the characteristics of the educational system in Serbia and the availability of schools providing intensive education in the second language, children belonging to different experimental groups were recruited from different schools. Although it would have been preferable if children had come from the same schools, we do not believe this to have had a significant impact on our results. All the schools that were included in the research are located in central parts of the city, the children attending them come from middle-class families, and the majority of their parents have completed university education, as reported by school principals. Although it was not possible to match socioeconomic status information provided by the school principals to each participant individually, which would have allowed us to enter socioeconomic status as a covariate in the statistical analysis, the three groups did not differ in this respect. Hence, the obtained group differences cannot be attributed to this factor.

In addition, in the current study children from the different schools were learning different languages. Although this is less than optimal because it is possible that linguistic specificities of these languages have a differential influence on the development of EFs, all second languages were Indo-European languages. Future studies might provide more definitive answers to the question of how typological factors bear on the influence of language learning on EFs.

Future research in this area should also attempt to shed more light on the relationship between the amount of exposure and length of *experience* with the second language and their joint effect on cognitive control in a bilingual setting. In the current study, a benefit was obtained in the domain of WM. However, the rather small sample size of this study is one of its limitations. Nevertheless, our findings extend previous research, demonstrating that daily length of exposure is a significant factor affecting executive control in early second-language acquisition immersion programs. Future research could explore when the bilingual advantage in other areas of EFs emerges in bilingual children with intensive immersion education.

Conclusions

This study investigated whether child second-language learners who attend two language immersion programs with different amounts of second-language exposure differ from their monolingual peers who attend mainstream monolingual schools with respect to a range of executive function tasks, including working memory, inhibition, and shifting. This study showed that differences between the high-exposure group and the monolingual control group emerged only in the area of WM but not for other EFs. These results help us to understand the role of WM during the early stages of intensive second-language learning and how it compares with other EFs that have been shown to be affected by bilingual exposure such as inhibition and shifting.

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