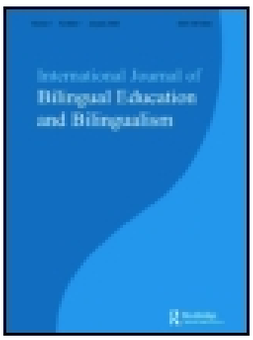

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Do executive functions gained through two-way dual-Language education translate into math achievement?

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ABSTRACT

Success in mathematics contributes to children's future career and lifelong financial security. There have been reports that dual-language education conveys academic advantages in mathematics achievement, although there is debate. This study aimed to investigate whether dual-language education benefits children's mathematics achievement and examine executive functions as a potential mechanism through which dual-language education influences math achievement. Fourth grade children ($n = 465$; aged 9–10 years) attending either dual-language education or mainstream education programs within the same school were tested on both mathematics achievement and executive functions. Results showed that children in the dual-language education program had higher math scores as well as higher executive functions performance. Executive functions also significantly mediated the relation between education program and mathematics achievement, providing support for executive functions as a mechanism through which advanced mathematics performance is achieved. All analyses controlled for primary caregiver education. Attrition rate of the education program as well as bilingual proficiency were considered in the analysis. Results suggest that bilingual experience gained from a dual-language program may benefit children's executive functions and that dual-language education may be an effective program for children's mathematics achievement through cognitive advantages that contribute to academic success.

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Two-way dual-language education; mathematics achievement; executive functions; bilingual proficiency

Having a solid foundation in mathematics contributes to children's later academic achievement (e.g. Duncan et al. 2007; Watts et al. 2014) and future career success and lifelong financial security (e.g. Lee 2012; Shapka, Domene, and Keating 2006). The importance and long-term impact of math achievement have inspired research in math education (e.g. Ashcraft and Krause 2007). Despite efforts, children in the United States are scoring below average on the math test of the Programme for International Student Assessment (PISA; OECD 2020). This calls for creative action.

In addition to second-language acquisition, dual-language education may be an effective program to enhance children's academic achievement, regardless of their home language. Children in dual-language education show higher academic performance compared to their peers in mainstream education programs (e.g. Collier and Thomas 2004; Gomez, Freeman, and Freeman 2005). Moreover, children participating in dual-language programs not only reported a high level of mathematics achievement (e.g. Gomez, Freeman, and Freeman 2005; Marian, Shook, and Schroeder 2013) but also faster growth of mathematics performance (Watzinger-Tharp, Swenson, and Mayne 2018) compared to their counter parts in mainstream monolingual education programs. This evidence

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suggest that dual-language education programs may be a promising intervention for children's mathematics achievement. However, the program can only be effectively implemented as an intervention if the factors contributing to the advantage are understood. Yet, the underlying mechanisms explaining why children in dual-language education are outperforming their peers in mathematical achievement have not been identified.

A large body of research has shown cognitive advantages of bilingualism that emerge from managing two different languages on a regular basis. Specifically, these studies have demonstrated that bilingual individuals have higher performance in executive functions tasks compared to their monolinguals peers (e.g. Bialystok and Barac 2012; Esposito and Baker-Ward 2013; Nicolay and Poncelet 2015; but see Paap, Johnson, and Sawi 2015 and Lowe et al. 2021 for discrepant findings that have questioned the generalizability of this effect). Importantly, executive functions are closely correlated to academic achievement broadly (e.g. Serpell and Esposito 2016) and mathematical achievement, specifically (Best, Miller, and Naglieri 2011; Blair and Razza 2007). Furthermore, executive functions are a strong predictor of concurrent (Magalhães et al. 2020) and later math achievement (Bull, Espy, and Wiebe 2008; Clark, Pritchard, and Woodward 2010). Thus, it may be that enhanced executive functions gained through bilingual education are a mechanism underlying high math achievement for children in dual-language education programs. We examined this in fourth grade students with the collaboration of a school system offering a dual-language track side-by-side with a mainstream education track. Specifically, we examined whether dual-language education presents an advantage in executive functions that mediates the relation between educational program and math performance.

Dual-language education

Bilingual education is an umbrella term which refers to education programs that involve teaching academic content through a target-language. Bilingual education includes immersion education, one-way dual-language education and two-way dual-language education. These programs aim to develop bilingualism, biliteracy and bicultural children. In immersion education programs, instruction is provided predominantly through a target-language (90–100%) and the students typically consist of the speakers of the majority-language of the region learning an alternative language (such as English speakers in a French immersion program in Canada). Dual-language programs typically provide content through both the majority-language and a target language, often 50% of instruction through each language (although the language composition varies across specific models). There are two main models of dual-language education, one-way and two-way, that differ in the composition of students. Two-way dual-language programs consist of both majority- and target-language speakers in relatively equal representation, whereas one-way dual-language programs consist of only one language group with either majority- or target-language speakers.

The differences in the bilingual education programs may be important for understanding how well they accomplish the goals of bilingualism, biliteracy, biculturalism, and academic achievement as well as the cognitive impact of participation. To best characterize these differences, we use the most appropriate term when reporting on previous literature. The current research is made possible with the cooperation of a school offering a two-way dual-language program and a mainstream all-English education program.

Studies have found lower dropout rates for ELLs in dual-language programs compared to those enrolled in English-only programs (Lindholm-Leary and Borsato 2001; Thomas and Collier 2002). Furthermore, children of all language backgrounds in dual-language programs achieve at least comparable to, and often higher than, their peers in mainstream language programs on standardized academic tests while also developing proficiency in a second-language (e.g. Collier and Thomas 2004; Gomez, Freeman, and Freeman 2005).

Dual-Language education and mathematics achievement

There is evidence supporting that dual-language education specifically impacts math achievement. Both ELLs and English-language speakers in dual-language education programs perform better or at least comparably to their peers in mainstream programs on math achievement (e.g. Barnett et al. 2007; Steele et al. 2017). For example, Watzinger-Tharp, Swenson, and Mayne (2018) compared the math scores of 2287 4th graders in dual-language and mainstream programs matched with demographic characteristics and 3rd grade math and English language arts scores. The results showed a significantly higher math score for the 4th graders in the dual-language program compared to their counterparts in mainstream programs, indicating a faster growth in math performance for dual-language program students. It appears to take several years of dual-language education for an advantage to emerge in mathematics, with no difference in lower grades but outperformance in higher grades regardless of home language (e.g. Esposito 2020; Padilla et al. 2013). Children from low socio-economic status (SES) backgrounds who are in dual-language programs also show advantages in math performance after a few years (Esposito 2020; Lindholm-Leary and Block 2010). For example, Marian, Shook, and Schroeder (2013) found higher math scores for children in dual-language programs regardless of language background and SES. Specifically, 5th grade speakers of the target language and 3rd, 4th, and 5th grade speakers of the majority-language had higher math scores than their peers in mainstream education program even though the dual-language program had a higher proportion of children from low income families (86.6% vs 47.8%).

In contrast to aforementioned studies, a recent meta-analysis questioned the academic advantages gained from dual-language programs. Hill (2018) conducted a meta-analysis including ten studies which examined the difference in academic achievement for children in dual-language and mainstream education programs. He found an advantage for dual-language students, but pointed out the small effect size. Also, Hill found notable variability among the effects of dual-language programs on mathematics achievement leaving the possibility that other confounding variables such as socioeconomic status, student attrition rate, and language proficiency may be involved. Accordingly, Hill posited a potential null effect of dual-language education. Thus, the potential for dual-language education as an intervention strategy for math performance is yet indeterminable and it is pivotal consider SES, attrition rates, and language proficiency to examine the effect of dual-language programs on children's math achievement.

Executive functions and mathematics achievement

Executive functions refer to top-down mental processes that support goal-directed behavior. It is generally accepted that executive functions consist of inhibition (suppression of prepotent or irrelevant information and responses), shifting (flexibly shifting between different tasks or rules), and updating (manipulating the contents stored in working memory as required; e.g. Miyake et al. 2000). A large body of research shows that executive functions correlate strongly with scholastic performance (e.g. Diamond 2013; Serpell and Esposito 2016), even explaining more variance in academic achievement than intelligence (Alloway, Bibile, and Lau 2013; Swanson 2004).

The relation between executive functions and math achievement has long been established across various age ranges from preschoolers to adults (e.g. Blair and Razza 2007; Magalhães et al. 2020). A cross-sectional study also found a significant correlation between executive functions and math from age 5 to 17 in a large US sample representative of demographics of the country (Best, Miller, and Naglieri 2011). The results indicate the lasting impact of executive functions on math performance. Moreover, longitudinal studies suggest robust relations between executive functions and mathematics achievement. Executive functions of preschoolers were related to their mathematics achievement concurrently as well as throughout their first three years of elementary school (Bull, Espy, and Wiebe 2008) and this longitudinal relation remained even after controlling for other variables such as socio-economic status (Bull et al. 2011) and reading achievement (Clark, Pritchard, and Woodward 2010).

Potential benefits for executive functions from dual-Language education

Bilingualism gained through natural exposure has a positive influence on some areas of children's cognitive development. This includes areas where the impact is well documented and robust (e.g. metalinguistic awareness, Barac & Bialystok, 2012; Zhang, Chin, and Li 2017) as well as areas with greater controversy (e.g. executive functions, Esposito, Baker-Ward, and Mueller 2013; Nicolay and Poncelet 2015; but see Lowe et al. 2021 for small effect from a meta-analyses). It is not known if the second-language experience and other aspects of dual-language education that make it differ from traditional classrooms, such as frequent language switching, support the development of executive functions. Studies that have examined this are limited. Among those studies, most focused on the impact of language immersion programs in which instructions and content are provided predominantly through a target language in order to enhance majority-language speaking children's second-language proficiency (immersion programs, such as French language immersion for English speaking children in Montreal; Bialystok and Barac 2012; Purić, Vuksanović, and Chondrogianni 2017). These studies indicate that bilingual experience gained through classroom exposure contributes to children's executive control, attention skills, inhibitory control and metalinguistic awareness. However, two-way dual-language programs differ from immersion education programs in ways that limit the generalizability of this extant research.

In two-way dual-language programs, instruction is provided approximately equally through two languages (although models vary) and children in two-way dual-language classroom consist of comparable number of speakers of both languages. This classroom designs requires more frequent use of code-switching between two languages whether from instruction or from interactions between classmates who speak different languages. Higher frequency of language switching demands may enhance executive functions; however, it is also possible that higher cognitive load may impede children from developing executive control ability. Indeed, the research thus far has been inconclusive. A few studies found no difference in executive functions between children in dual-language and mainstream education programs (Kaushanskaya, Gross, and Buac 2014; Poarch and van Hell 2012). One study indicated a disadvantage for children in bilingual education (Purić, Vuksanović, and Chondrogianni 2017). However, children in these studies had less than two years of experience in a dual-language program. Findings from studies with children who had been in dual-language programs longer indicate there may be an advantage with additional experience. Esposito and Baker-Ward (2013) found a cognitive advantage for children from economically disadvantaged families in the Trail Making Task, but only for children with more than 3 years of experience in the program. In addition, Esposito (2020) found benefits in executive functions in behavioral rating measures for all grade levels in a two-way dual-language education program. Thus, there is some support that the bilingualism gained through dual-language education could support emerging benefits in executive functions.

If benefits are found, it is yet unclear whether bilingual proficiency or other aspects of dual-language education, such as sufficient experience switching between two languages, are responsible for emerging cognitive advantages. Some studies have shown that the advantage in executive functions emerge when children achieve sufficient proficiency in both languages (Clarkson 1992; Kempert, Saalbach, and Hardy 2011). Additionally, Yim and Bialystok (2012) found that more frequent use of code-switching was associated with better switching on an executive functions measure. This indicates the importance of considering both children's proficiency in their languages as well as the context of language use in order to better understand the mechanism supporting any benefit to executive functions found associated with dual-language education.

Another concern regarding the potential impact of dual-language education on cognitive development is whether it would transfer to academic performance. Transfer refers to an effect that knowledge, strategies, skills, etc. acquired in one context through training applies to other contexts. Studies of far transfer (i.e. a generalization of an effect of specific training to distant domains) remain elusive (e.g. Barnett and Ceci 2002; Jaeggi et al. 2014). While a number of studies found far

transfer in various domains including reading comprehension (e.g. García-Madruga et al. 2013), executive functions (e.g. Salminen, Strobach, and Schubert 2012), and mathematics (e.g. Witt 2011), there is also notable evidence that such effects do not exists (e.g. Jacob and Parkinson 2015; Zinke et al. 2014) or are at least difficult to induce under experimental conditions. The current study sheds light on the far transfer of executive functions in educational settings by examining whether advantages in executive functions from attending dual-language education translate to mathematics performance.

In summary, there are three uncertainties regarding the relation between dual-language education and executive functions. First, whether dual-language education conveys a cognitive advantage in executive functions. Second, if it does, is the advantage related to the education environment more generally or specifically related to bilingual proficiency. Third, if there is an advantage to executive functions for those in the dual-language education model, does this transfer to academic performance such that executive functions mediate the relation between education program and math achievement.

The current study

The main purpose of our study was to examine a mechanism for high mathematical achievement in children participating in dual-language education programs compared to their peers in mainstream monolingual programs. To address this, we examined (1) whether children in the dual-language education program had higher mathematics achievement compared to their peers in mainstream classrooms, (2) whether children in the dual-language program showed evidence of higher executive function skills compared to their peers in mainstream education, and, if higher achievement was found in both areas, (3) did executive functions performance mediate the relation between education program and mathematics achievement. Additionally, we examined whether executive functions and academic performance were predicted by bilingual proficiency or enrollment in dual-language education to better understand whether any advantage found was related to the educational context conveyed through dual-language education or specific to language proficiency. Bilingual proficiency is being gained by children within both educational models (because children who speak Spanish at home are still developing both languages even if attending the monolingual education model). Thus, we could examine whether bilingual proficiency alone had the same impact on executive functions and math achievement as participation in dual-language education (which is contributing to gains in bilingual proficiency but also creates a bilingual context).

We predicted higher mathematics achievement and executive function skills for children in the dual-language program compared to their peers in the mainstream education program and that executive functions would mediate the relation between education program and mathematics achievement. We also predicted that bilingual proficiency would explain variance in mathematics achievement and that executive functions would mediate the relation between bilingual proficiency and mathematics achievement. The present study was conducted with 4th graders. They were chosen specifically as they had sufficient experience in a two-way dual-language education program.

Method

Participants and school system

The participants were 465 4th grade children (54% girls, $M_{age} = 10$ years, 4 months, $SD_{age} = 5.50$), enrolled in a rural public school in the southeastern United States (see Table 1). The data was drawn from a larger study which consist of 481 4th graders (16 participants were excluded for missing the math test score). Participants were recruited annually across 3 years (2016-2018) with letters distributed by their teachers and only those children whose parents/guardians provided written consent participated (the *n* represents 67% of population). The school system includes 266 mi^2 with one public school option for Grade 4. Reflecting the diversity of the community, the

Table 1. Descriptive statistics by education program.

	Education program	
	Dual-language program	Mainstream education program
n (female;male)	118 (66;50)	358 (180;163)
Strongest Language (Spanish;English)	96 (32;64)	255 (34;221)
Caregiver Education	3.30 (1.78)	3.90 (1.80)
	$n = 110$	$n = 339$
BST (ms)	888.71 (143.78)	935.58 (139.11)
	$n = 104$	$n = 255$
Simon (ms)	913.82 (140.67)	946.50 (134.96)
	$n = 64$	$n = 172$
English verbal comprehension	47.87 (7.63)	48.93 (7.01)
	$n = 99$	$n = 235$
Spanish verbal comprehension	30.74 (21.51)	12.79 (18.85)
	$n = 104$	$n = 244$
Bilingual Proficiency	83.63 (16.65)	74.57 (16.74)
	$n = 80$	$n = 103$
Math EOG	449.59 (7.63)	445.04 (9.34)
	$n = 116$	$n = 349$

Notes. Bilingual Proficiency was derived from sum of English and Spanish Verbal Comprehension score. Caregiver Education was used as a measure of socio-economic status.

sample was comprised of 35% Black, 22% non-Hispanic White, and 18% Hispanic White. Remaining 18% identified as Hispanic or Latino, however, they did not specify a race.

As described, the school system offers two educational tracks: mainstream English (monolingual English education) or two-way dual-language (TWDL; Spanish/English; 50% split instructional time and equal representation of speakers of both languages in the classroom). Attrition in the sample was low. Only 4 children included in the sample moved out of the TWDL and into the mainstream English program. All other children whose data was included in this study enrolled in their education program in kindergarten and maintained a stable placement. The education programs are housed within the same school with the same school-level resources. All children placed in the TWDL program are placed by lottery (opt-in at kindergarten registration), but not all children in mainstream English entered the lottery (the percentage of parents who enter the lottery is not available). Previous studies within this population have not found differences in observable characteristics between children or families that are in the TWDL compared to the mainstream English model (e.g. Esposito 2020).

Measures

The task battery consisted of language measures, academic measures, and executive function measures.

Bilingual proficiency

The Woodcock-Muñoz Language Survey® -Revised Normative Update (*WMLS® -R NU*) is a norm referenced measure of verbal comprehension, available in both English and Spanish, and is appropriate for ages 2–90 + . We used both English and Spanish language comprehension measures: Verbal Comprehension Test 1, vocabulary, and Test 2, analogies; both tests were administered in both languages. Raw scores within each language were recorded to calculate verbal comprehension measures, one in English and one in Spanish. These were then summed to create one measure of bilingual proficiency. Children who scored 0 either in Spanish or English were excluded while generating the sum score as they were not quantifiably bilingual.

Parent and academic data

Parents completed a written questionnaire including family demographics and students' language history (see Table 1). Parents provided the highest education of the primary caregiver, which was

used as a proxy for SES (e.g. Davis-Kean 2005; Waters et al. 2021). With parental authorization, the school guidance counselors provided scores on the state standardized end-of-grade mathematics test (math EOG). The test is administered to fourth graders in all public schools in North Carolina. We analyzed the raw scores of math EOG (*range* = 426-475).

Computerized executive functions measures

Computerized tasks used the Psychology Experiment Building Language (PEBL: Mueller 2010, 2012) delivered on TP500L laptop computers with touchscreen monitors.

Bivalent shape task. The Bivalent Shape task (stimulus-stimulus conflict: Mueller and Esposito 2014) is a non-verbal computerized test measuring the ability to suppress irrelevant salient features and act on relevant stimuli where the conflicts exist. Two shape buttons remain on the screen (i.e. a red circle on the left and a blue square on the right) and participants use the buttons to 'match the shape' to a larger shape presented mid-screen (circles and squares in either red, blue, or a black outline). Congruent stimuli matched in both color and shape; incongruent items matched in shape but not in color; and neutral items did not have color, giving no distraction or facilitation to participants. The task starts with practice blocks for each type of stimuli followed by a mixed block with all three types of stimuli presented in a fixed randomized order of 10 trials. Participants had up to 3 s to respond to each of the trials. Mean reaction times on correct trials for the incongruent stimuli were used in the analysis. This task has been used with preschool bilingual children (Esposito, Baker-Ward, and Mueller 2013) and 8- to10-year-olds (Esposito and Bauer 2018).

Simon task. The Simon task measures inhibitory control ability that involves a stimulus-response conflict. A green or orange rectangle appears on the left or right side of the monitor and participants are asked to press the shift button on each end that correlates to the color, ignoring the location of the shapes on the screen. If the shape on the screen is on the same side of the shift button, individuals respond more quickly. The Simon task has been validated with other executive functions as a marker of attention deficit for children (e.g. Mullane et al. 2009) and has been employed in studies examining cognitive effects of bilingualism (e.g. Martin-Rhee and Bialystok 2008). Mean reaction times for correct trials for incongruent trial types were used in the analysis. This task was only collected in two of the three years of data collection.

Procedures

Children were tested individually within their school during a single session lasting approximately 45 min, which is the time allotted by the participating school system. Research assistants were psychology college students with intermediate to advanced Spanish ability. They were extensively trained and were monitored by the last author during data collection to ensure protocol fidelity. All participating children provided verbal assent. The university institutional review board and participating school system school board reviewed and approved all procedures. The computer tasks were administered in random order. Both computer tasks were designed to be non-verbal and instructions were administered in the child's preferred language (English or Spanish). Computer tasks were followed by the language measures, Spanish then by English. These measures were included as part of a more extensive test battery.

Results

The results are reported in four sections. First, we describe student's executive functions, mathematics achievement, and correlations. Second, we examine differences in mathematics achievement and executive functions across the two education groups. Third, we evaluated whether the advantage in executive functions mediated the relation between education program and mathematics achievement.

Lastly, we explored the role of bilingual proficiency in the mediation model. The effect of education program and bilingual proficiency were separately examined as bilingual proficiency is deeply embedded in dual-language. Examining the bilingual proficiency in separate model enabled us to investigate whether any effect found in the TWDL program could best be explained by gains in bilingual proficiency or if there was an added component from the context of the education program. All data analysis were conducted using two tailed tests with *R* 3.6.2 software (R Core Team 2020).

Description and correlations

Means and standard deviations are reported in Table 1. Correlations are shown in Table 2. Math EOG was significantly related to Executive Functions as well as Bilingual Proficiency. Since Caregiver Education was significantly correlated with Education Program, Mathematics Achievement, and English and Spanish Verbal Comprehension, all analyses controlled for the effect of Caregiver Education. The number of participants for the BST and Simon tasks differed because Simon was not administered in all years. Additionally, the BST and Simon task were not highly correlated to each other. Thus, we ran separate models for Simon and BST for the following analysis.

Education group differences

We examined whether students across the two education programs differed in math achievement and executive functions while controlling for Caregiver Education. The results of the analysis of covariance (ANCOVA) showed that children in different education programs differed in math achievement [$F(1, 436) = 31.39$, $p < .001$, *partial* $\eta^2 = .07$], such that children in the TWDL program had higher Math EOG scores compared to their peers in mainstream English education (*adj. M* = 450.28 vs 444.82) after controlling for Caregiver Education. Children also differed significantly across education programs in executive functions. This was the case for both the BST [$F(1, 335) = 8.17$, $p < .01$, *partial* $\eta^2 = .02$] and the Simon [$F(1, 224) \quad 4.63$, $p < .05$, *partial* $\eta^2 = .02$]. Children in the TWDL program showed faster response times in the conflict trials for both the BST (*adj. M* = 885.65 vs 934.22) and the Simon (*adj. M* = 904.87 vs 949.57) with Caregiver Education controlled.

Mediation analysis

We examined whether executive functions mediated the relation between education program and math achievement. Following the steps of Baron and Kenny (1986), we examined: (1) whether Education Program predicted Math Achievement, (2) whether Executive Functions (represented by BST and Simon task in separate models) were predicted by Education Program, and (3) whether the effect of Education Program on Math Achievement decreased when Executive Functions and Education Program were both included in the regression analysis. The regression models predicting Executive Functions with Caregiver Education and Education Program as predictors were examined respectively for the BST and the Simon task with consistent results (see Figure 1 and Figure 2). In both models, Education Program predicted Math Achievement [$F(2,436) \quad 22.55$, $p < .001$, $\eta^2 = .09$] and

Table 2. Correlation analysis.

	1.	2.	3.	4.	5.	6.	7.
1. Gender	1.00						
2. Caregiver education	−0.08	1.00					
3. Education program	0.04	−0.16**	1.00				
4. BST	0.05	−0.01	−0.15**	1.00			
5. Simon	0.09	−0.12	−0.11	0.46***	1.00		
6. Bilingual Proficiency	0.04	−0.35***	0.26***	−0.09	−0.03	1.00	
7. Math EOG	−0.06	0.17***	0.22***	−0.25***	−0.30***	0.33***	1.00

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

Executive Functions [$F(2,336)$ 4.23, $p < .05$, $\eta^2 = .02$ for BST; and $F(2,226)$ 3.99, $p < .05$, $\eta^2 = .03$ for Simon]. The relation between Education Program and Math Achievement decreased with the addition of the Executive Functions measure [$F(3,334)$ 18.03, $p < .001$, $\eta^2 = .13$ for BST; and $F(3,223)$ 16.99, $p < .001$, $\eta^2 = .18$ for Simon]. This indicates mediation. To examine whether this mediation was significant, we then conducted the Sobel test. The Sobel test revealed that the mediation model with the BST ($Z = 2.37$, $SE = .28$, $p = .02$) was statistically significant, however, the mediation model with the Simon task was not ($Z = 1.91$, $SE = .40$, $p = .06$).

Bilingual proficiency

We next investigated whether bilingual proficiency (i.e. a sum score of Spanish and English measure), explains the variance of math achievement and executive functions. These analyses included only those for whom a bilingual proficiency score could be calculated (scored above 0 on both Spanish and English measures; see supplemental materials for alternative analysis based on more stringent qualifications), but did not divide students by education program. We again followed the steps outlined by Baron and Kenny (1986), replacing Education Program with Bilingual Proficiency. First, the regression model including Caregiver Education and Bilingual Proficiency as predictors significantly explained children's Math EOG [$F(2,168)$ 23.01, $p < .001$, $\eta^2 = .21$]. Next, the regression model including Caregiver Education and Bilingual Proficiency significantly explained BST [$F(2,163)$ 3.57, $p < .05$, $\eta^2 = .03$]. Finally, the regression model with Caregiver Education, Bilingual Proficiency, and BST predicting Math EOG was significant [$F(3,162)$ 19.89, $p < .001$, $\eta^2 = .26$; see Figure 3]. Although all steps of regression models were significant, the Sobel test revealed that the mediation was not significant ($Z = 1.77$, $SE = .01$, $p = .08$). We next examined the regression models with Simon. A regression model with Caregiver Education and Bilingual Proficiency explaining for Simon was not significant [$F(2, 93)$ .28, $p = .75$], indicating no support for the mediating role of executive functions in relation between Bilingual Proficiency and Math EOG (see Figure 4).

Discussion

This study examined whether children in a TWDL program had higher mathematics achievement compared to their peers in a mainstream education program and whether the higher performance

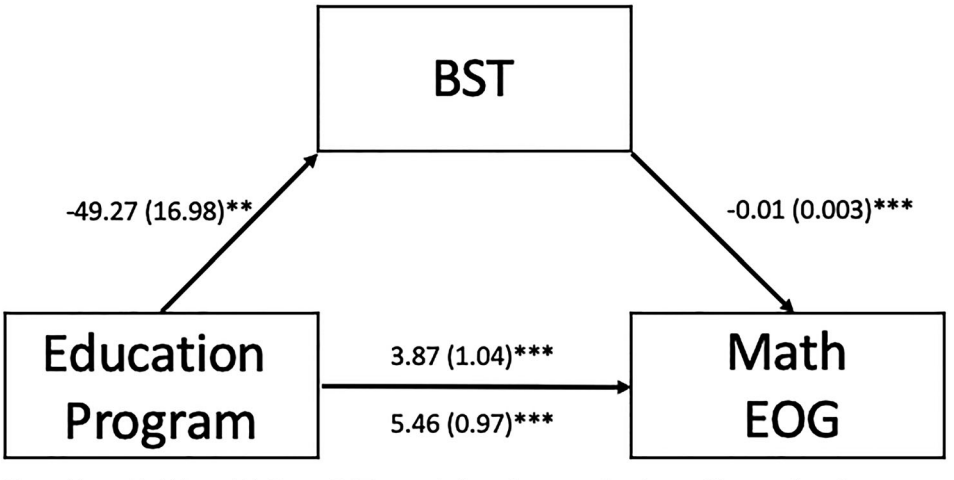

Figure 1. Mediation Analysis Examining Whether BST Mediates Between Education Program and Math EOG Controlling for Caregiver Education. Notes. **$p < .01$. ***$p < .001$. Lower BST scores indicate faster reaction time and better task performance.

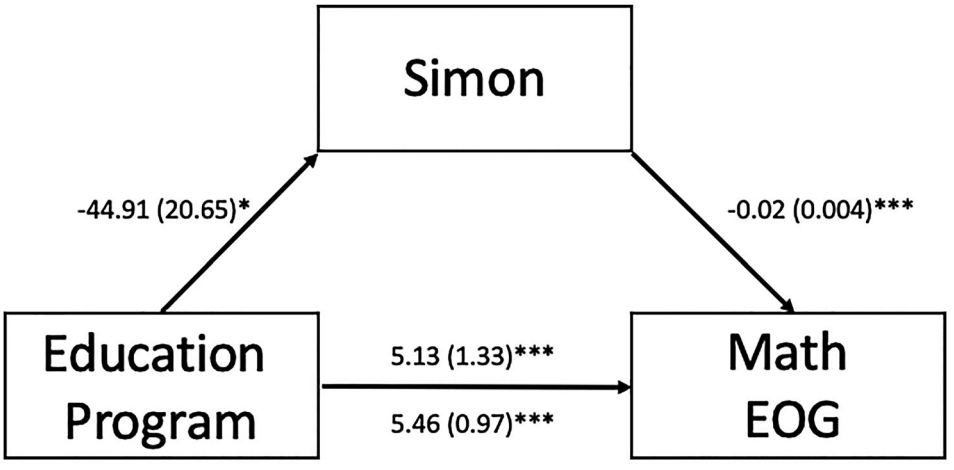

Figure 2. Mediation Analysis Examining Whether Simon Mediates Between Education Program and Math EOG Controlling for Caregiver Education. Notes. *$p < .05$. ***$p < .001$. Lower Simon scores indicate faster reaction time and better task performance.

was explained by executive functions. The results supported that children in TWDL have higher performance in both mathematics achievement and executive functions compared to their peers in mainstream education even when controlling for caregiver education. Children in TWDL showed higher math standardized test scores as well as faster response times in both Simon and BST tasks. We also found support for the theory that executive functions was an underlying mechanism of the higher mathematics achievement in TWDL children. Further, our results indicate that the experience of participating in a TWDL program may be partially driving the advanced performance. This advantage was not solely due to gained proficiency in the languages as the results did not replicate when education program was replaced with bilingual proficiency and included students gaining proficiency in the mainstream English-only program.

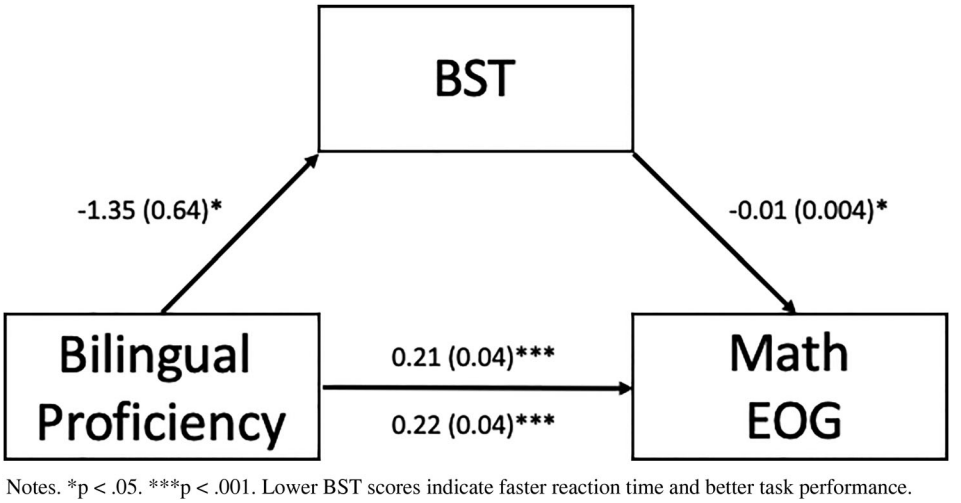

Figure 3. Mediation Analysis Examining Whether BST Mediates Between Bilingual Proficiency and Math EOG Controlling for Caregiver Education. Notes. *$p < .05$. ***$p < .001$. Lower BST scores indicate faster reaction time and better task performance.

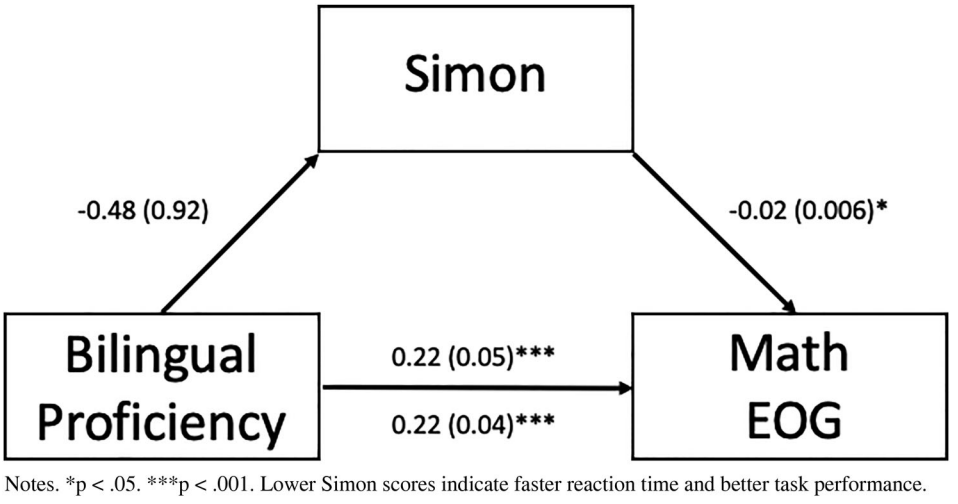

Figure 4. Mediation Analysis Examining Whether Simon Mediates Between Bilingual Proficiency and Math EOG Controlling for Caregiver Education. Notes. *$p < .05$. ***$p < .001$. Lower Simon scores indicate faster reaction time and better task performance.

Our findings support higher math performance for students enrolled in a TWDL program compared to their peers in a mainstream English-only program, even after considering other possible confounding variables. Previously, Hill (2018) proposed the possibility of a null effect for dual-language on children's academic achievement pointing out the high variability of the mathematics achievement that might have been driven by other factors such as SES and attrition rate. SES has been known as a strong indicator for children's academic achievement (see Sirin 2005 for meta-analysis), as lower SES can mean fewer resources available in their family and community (e.g. Evans 2004). The proxy we had to represent SES in this study was caregiver education. We controlled for this in all of the analysis and, importantly, caregiver education was lower for those in the TWDL program compared to the mainstream English model. Although caregiver education is an imperfect proxy for socio-economic status, this is an indication that socio-economic status was unlikely to be higher for TWDL students as parental education is highly tied to socio-economic status (e.g. Davis-Kean 2005; Waters et al. 2021). In addition, only 4 of the 465 participants moved between education programs (all four moved from the TWDL to the mainstream program, and in the analyses, they are included in the mainstream program), representing a low attrition rate for TWDL program in our sample. Thus, these factors are not likely to be responsible for the difference found in academic performance between the two educational programs. Hence, we hold that participating in TWDL is contributing to mathematics achievement.

The variability in Hill (2018)'s meta-analysis might be explained by the number of years spent in the educational program, a factor he did not take into consideration. Previous studies that have shown higher academic achievement for children in dual-language programs included those enrolled in dual-language for more than three years (e.g. Marian, Shook, and Schroeder 2013; Steele et al. 2017). This suggests that the years of experience being in the program may be the key factor that supports the emergence of academic achievement in mathematics. Perhaps the academic benefits take time to emerge or require more experience.

Years of experience in dual-language may be a crucial factor when studying the academic achievement of bilingual education program for two main reasons. First, it may take time to develop the executive functions skills that affect educational achievement. It may be that children must gain sufficient experience language switching either through instructions or interacting with peers with different language backgrounds before a benefit can develop. The constant demand of managing and switching languages throughout the day in bilingual education may contribute

to their cognitive development. Second, early academic achievement might be hindered by low vocabulary in at least one of the languages of instruction. When children enter the TWDL program, they might have insufficient vocabulary in either the target- or majority-language to comprehend academic content. However, as children spend more time learning through two languages, their vocabulary increases and, combined with growth in executive functions, they are able to benefit academically. Thus, we recommend considering years of experience in the education program when studying cognitive development and academic achievement of children in bilingual education.

Further, we posit that enhanced cognitive ability from frequent language switching rather than bilingual proficiency alone may be driving children's subsequent mathematics achievement and add to previous evidence of far transfer. Specifically, while executive functions mediated the relation between education program and mathematics achievement, the mediation model between bilingual proficiency (that included children across education models) and mathematics achievement was not significant. Our findings do not counter previous research on bilingual proficiency being an important factor for the cognitive advantage to emerge. Bilingual proficiency was significantly related to executive functions. However, our results suggest that even though bilingual proficiency contributes to academic and cognitive advantages, bilingual experience in classrooms may be a more important factor in supporting a cognitive advantage that translates to children's academic achievement. It may be that children in the TWDL program have higher demands for language switching while those not in the program are able to compartmentalize language between home and school contexts, providing less demand on the executive system (Grosjean 2010; Yim and Bialystok 2012).

While our results support the possible advantage of TWDL in executive functions and further mathematics achievement, we also note that the current study design cannot determine a causal relation. Specifically, the sample did not result from the randomization process, and there are likely factors involved in who entered the lottery and who did not that also contribute to differences in educational outcomes. For example, it is likely that Spanish-speaking families would sign up for the TWDL more than monolingual families. Moreover, while parents sign up for the lottery, their perception of their child's success in such education program may be involved. Although no observable characteristics have been found between TWDL and mainstream education model (see Esposito 2020), this does not eliminate group differences as important to the observed educational outcomes. Indeed, the model here explained 13% (a model with BST) and 18% (a model with Simon) of the variance, indicating many factors are involved.

The present investigation is not without limitations. First, the data reported are from a cross-sectional quasi-experimental design that cannot identify causality. Given the interesting findings, a fruitful direction for future work will be to collect longitudinal data that includes the measures from prior to entrance into the educational program. Second, we had a limited number of data available for the Simon task. We were missing the Simon task data for an academic year (2017) which yielded a smaller sample size ($n = 236$) compared to BST ($n = 449$). It is entirely possible that the null results are due to reduced power and, thus, the results should be interpreted with caution. Further research is recommended assessing executive functions with a large number of tasks and a large sample size to inform the generalizability of the reported BST findings to other areas of executive functions. We also note that we had a single indicator available as a proxy for socio-economic status, caregiver education. There are multiple indicators such as parental occupations and household income that would help to better understand the role socio-economic status plays in educational outcomes between education programs. Although parental occupations have been widely used to represent family backgrounds (Marks 2011), there is evidence suggesting that children's outcome including academic achievement may differ according to how it is measured (e.g. Festin et al. 2017; Marks 2011). Thus, exploring the mechanism of academic advantage in bilingual education considering multiple measures of SES is a direction for future research. The study is also based on a US rural sample and, although racially and ethnically diverse, cannot be assumed to generalize to other contexts, including those outside the US.

In conclusion, the current study provides support for the hypothesis that executive functions works as a mechanism supporting high math achievement in children enrolled in TWDL. These results held with caregiver education controlled and with a sample that has very low attrition. The implication is that, in addition to gaining both fluency and literacy in a second-language while supporting the first language, children in TWDL are gaining cognitive skills that support mathematical achievement. The results provide support that the benefits are not just the result of gaining language proficiency, but also the context of a TWDL program. Future research can examine how this educational and linguistic environment support cognitive development. Therefore, we suggest the continued research of TWDL as an effective educational program and compelling strategy to support mathematical achievement. The results support the continued expansion of two-way dual-language programs for both language development and academic achievement.

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References

Alloway, T. P., V. Bibile, and G. Lau. 2013. "Computerized Working Memory Training: Can it Lead to Gains in Cognitive Skills in Students?" *Computers in Human Behavior* 29 (3): 632–638.

Ashcraft, M. H., and J. A. Krause. 2007. "Working Memory, Math Performance, and Math Anxiety." *Psychonomic Bulletin & Review* 14 (2): 243–248.

Barac, R., and E. Bialystok. 2012. "Bilingual Effects on Cognitive and Linguistic Development: Role of Language, Cultural Background, and Education." *Child Development* 83 (2): 413–422.

Barnett, S. M., and S. J. Ceci. 2002. "When and Where do we Apply What we Learn?: A Taxonomy for far Transfer." *Psychological Bulletin* 128 (4): 612.

Barnett, W. S., D. J. Yarosz, J. Thomas, K. Jung, and D. Blanco. 2007. "Two-way and Monolingual English Immersion in Preschool Education: An Experimental Comparison." *Early Childhood Research Quarterly* 22 (3): 277–293.

Baron, R. M., and D. A. Kenny. 1986. "The Moderator–Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations." *Journal of Personality and Social Psychology* 51 (6): 1173.

Best, J. R., P. H. Miller, and J. A. Naglieri. 2011. "Relations Between Executive Function and Academic Achievement from Ages 5 to 17 in a Large, Representative National Sample." *Learning and Individual Differences* 21 (4): 327–336.

Bialystok, E., and R. Barac. 2012. "Emerging Bilingualism: Dissociating Advantages for Metalinguistic Awareness and Executive Control." *Cognition* 122 (1): 67–73.

Blair, C., and R. P. Razza. 2007. "Relating Effortful Control, Executive Function, and False Belief Understanding to Emerging Math and Literacy Ability in Kindergarten." *Child Development* 78 (2): 647–663.
Bull, R., K. A. Espy, and S. A. Wiebe. 2008. "Short-term Memory, Working Memory, and Executive Functioning in Preschoolers: Longitudinal Predictors of Mathematical Achievement at age 7 Years." *Developmental Neuropsychology* 33 (3): 205–228.
Bull, R., K. A. Espy, S. A. Wiebe, T. D. Sheffield, and J. M. Nelson. 2011. "Using Confirmatory Factor Analysis to Understand Executive Control in Preschool Children: Sources of Variation in Emergent Mathematic Achievement." *Developmental Science* 14 (4): 679–692.
Clark, C. A. C., V. E. Pritchard, and L. J. Woodward. 2010. "Preschool Executive Functioning Abilities Predict Early Mathematics Achievement." *Developmental Psychology* 46 (5): 1176.
Clarkson, P. C. 1992. "Language and Mathematics: A Comparison of Bilingual and Monolingual Students of Mathematics." *Educational Studies in Mathematics* 23 (4): 417–429.
Collier, V. P., and W. P. Thomas. 2004. "The Astounding Effectiveness of Dual Language Education for All." *NABE Journal of Research and Practice* 2 (1): 1–20.
Davis-Kean, P. E. 2005. "The Influence of Parent Education and Family Income on Child Achievement: The Indirect Role of Parental Expectations and the Home Environment." *Journal of Family Psychology* 19 (2): 294.
Diamond, A. 2013. "Executive Functions." *Annual Review of Psychology* 64: 135–168.
Duncan, G. J., C. J. Dowsett, A. Claessens, K. Magnuson, A. C. Huston, P. Klebanov, L. S. Pagani, L. Feinstein, M. Engel, and J. Brooks-Gunn. 2007. "School Readiness and Later Achievement." *Developmental Psychology* 43 (6): 1428.
Esposito, A. G. 2020. "Executive Functions in two-way Dual-Language Education: A Mechanism for Academic Performance." *Bilingual Research Journal* 43 (4): 417–432.
Esposito, A. G., and L. Baker-Ward. 2013. "Dual-language Education for low-Income Children: Preliminary Evidence of Benefits for Executive Function." *Bilingual Research Journal* 36 (3): 295–310.
Esposito, A. G., L. Baker-Ward, and S. T. Mueller. 2013. "Interference Suppression vs. Response Inhibition: An Explanation for the Absence of a Bilingual Advantage in Preschoolers' Stroop Task Performance." *Cognitive Development* 28 (4): 354–363.
Esposito, A. G., and P. J. Bauer. 2018. "Building a Knowledge Base: Predicting Self-Derivation Through Integration in 6-to 10-Year-Olds." *Journal of Experimental Child Psychology* 176: 55–72.
Evans, L. D. 2004. "Academic Achievement of Students in Foster Care: Impeded or Improved?" *Psychology in the Schools* 41 (5): 527–535.
Festin, K., K. Thomas, J. Ekberg, and M. Kristenson. 2017. "Choice of Measure Matters: A Study of the Relationship Between Socioeconomic Status and Psychosocial Resources in a Middle-Aged Normal Population." *PLoS One* 12 (8): e0178929.
García-Madruga, J. A., M. R. Elosúa, L. Gil, I. Gómez-Veiga, JÓ Vila, I. Orjales, and A. Contreras. 2013. "Reading Comprehension and Working Memory's Executive Processes: An Intervention Study in Primary School Students." *Reading Research Quarterly* 48 (2): 155–174.
Gomez, L., D. Freeman, and Y. Freeman. 2005. "Dual Language Education: A Promising 50–50 Model." *Bilingual Research Journal* 29 (1): 145–164.
Grosjean, F. 2010. "Bilingualism, Biculturalism, and Deafness." *International Journal of Bilingual Education and Bilingualism* 13 (2): 133–145.
Hill, S. R. 2018. "*A Meta-Analysis of the Effect of Ten Language Immersion Programs on Academic Achievement*." Volume 4 Fall 2018, 23.
Jacob, R., and J. Parkinson. 2015. "The Potential for School-Based Interventions That Target Executive Function to Improve Academic Achievement: A Review." *Review of Educational Research* 85 (4): 512–552.
Jaeggi, S. M., M. Buschkuehl, P. Shah, and J. Jonides. 2014. "The Role of Individual Differences in Cognitive Training and Transfer." *Memory & Cognition* 42 (3): 464–480.
Kaushanskaya, M., M. Gross, and M. Buac. 2014. "Effects of Classroom Bilingualism on Task-Shifting, Verbal Memory, and Word Learning in Children." *Developmental Science* 17 (4): 564–583.
Kempert, S., H. Saalbach, and I. Hardy. 2011. "Cognitive Benefits and Costs of Bilingualism in Elementary School Students: The Case of Mathematical Word Problems." *Journal of Educational Psychology* 103 (3): 547.
Lee, J. 2012. "College for all: Gaps Between Desirable and Actual P–12 Math Achievement Trajectories for College Readiness." *Educational Researcher* 41 (2): 43–55.
Lindholm-Leary, K., and N. Block. 2010. "Achievement in Predominantly low SES/Hispanic Dual Language Schools." *International Journal of Bilingual Education and Bilingualism* 13 (1): 43–60.
Lindholm-Leary, K. J., and G. Borsato. 2001. *Impact of two-way Bilingual Elementary Programs on Students' Attitudes Toward School and College*. Santa Cruz: Center for Research on Education, Diversity and Excellence, University of California.
Lowe, C. J., I. Cho, S. F. Goldsmith, and J. B. Morton. 2021. "The Bilingual Advantage in Children's Executive Functioning is not Related to Language Status: A Meta-Analytic Review." *Psychological Science* 32 (7): 1115–1146.
Magalhães, S., L. Carneiro, T. Limpo, and M. Filipe. 2020. "Executive Functions Predict Literacy and Mathematics Achievements: The Unique Contribution of Cognitive Flexibility in Gades 2, 4, and 6." *Child Neuropsychology* 26 (7): 934–952.

Marian, V., A. Shook, and S. R. Schroeder. 2013. "Bilingual two-way Immersion Programs Benefit Academic Achievement." *Bilingual Research Journal* 36 (2): 167–186.
Marks, G. N. 2011. "Issues in the Conceptualisation and Measurement of Socioeconomic Background: Do Different Measures Generate Different Conclusions?" *Social Indicators Research* 104 (2): 225–251.
Martin-Rhee, M. M., and E. Bialystok. 2008. "The Development of two Types of Inhibitory Control in Monolingual and Bilingual Children." *Bilingualism: Language and Cognition* 11 (1): 81–93.
Miyake, A., N. P. Friedman, M. J. Emerson, A. H. Witzki, A. Howerter, and T. D. Wager. 2000. "The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis." *Cognitive Psychology* 41 (1): 49–100.
Mueller, Shane T. 2010. "A Partial Implementation of the BICA Cognitive Decathlon Using the Psychology Experiment Building Language (PEBL)." *International Journal of Machine Consciousness* 2 (02): 273–288.
Mueller, S. T. 2012. The Psychology Experiment Building Language (Version 0.13)[Computer software].
Mueller, S. T., and A. G. Esposito. 2014. "Computerized Testing Software for Assessing Interference Suppression in Children and Adults: The Bivalent Shape Task (BST)." *Journal of Open Research Software* 2 (1): e3.
Mullane, J. C., P. V. Corkum, R. M. Klein, and E. McLaughlin. 2009. "Interference Control in Children with and Without ADHD: A Systematic Review of Flanker and Simon Task Performance." *Child Neuropsychology* 15 (4): 321–342.
Nicolay, A.-C., and M. Poncelet. 2015. "Cognitive Benefits in Children Enrolled in an Early Bilingual Immersion School: A Follow up Study." *Bilingualism: Language and Cognition* 18 (4): 789–795.
OECD. 2020. "Mathematics performance (PISA) (indicator)." Accessed on 26 September 2020. doi:10.1787/04711c74-en.
Paap, K. R., H. A. Johnson, and O. Sawi. 2015. "Bilingual Advantages in Executive Functioning Either do not Exist or are Restricted to Very Specific and Undetermined Circumstances." *Cortex* 69: 265–278.
Padilla, A. M., L. Fan, X. Xu, and D. Silva. 2013. "A Mandarin/English two-way Immersion Program: Language Proficiency and Academic Achievement." *Foreign Language Annals* 46 (4): 661–679.
Poarch, G. J., and J. G. van Hell. 2012. "Executive Functions and Inhibitory Control in Multilingual Children: Evidence from Second-Language Learners, Bilinguals, and Trilinguals." *Journal of Experimental Child Psychology* 113 (4): 535–551.
Purić, D., J. Vuksanović, and V. Chondrogianni. 2017. "Cognitive Advantages of Immersion Education After 1 Year: Effects of Amount of Exposure." *Journal of Experimental Child Psychology* 159: 296–309.
R Core Team. 2020. "R: A Language and Environment for Statistical Computing." R Foundation for Statistical Computing, Vienna, Austria.URL https://www.R-project.org/.
Salminen, T., T. Strobach, and T. Schubert. 2012. "On the Impacts of Working Memory Training on Executive Functioning." *Frontiers in Human Neuroscience* 6: 166.
Serpell, Z. N., and A. G. Esposito. 2016. "Development of Executive Functions: Implications for Educational Policy and Practice." *Policy Insights from the Behavioral and Brain Sciences* 3 (2): 203–210.
Shapka, J. D., J. F. Domene, and D. P. Keating. 2006. "Trajectories of Career Aspirations Through Adolescence and Young Adulthood: Early Math Achievement as a Critical Filter." *Educational Research and Evaluation* 12 (4): 347–358.
Sirin, S. R. 2005. "Socioeconomic Status and Academic Achievement: A Meta-Analytic Review of Research." *Review of Educational Research* 75 (3): 417–453.
Steele, J. L., R. O. Slater, G. Zamarro, T. Miller, J. Li, S. Burkhauser, and M. Bacon. 2017. "Effects of Dual-Language Immersion Programs on Student Achievement: Evidence from Lottery Data." *American Educational Research Journal* 54 (1_suppl): 282S–306S.
Swanson, H. L. 2004. "Working Memory and Phonological Processing as Predictors of Children's Mathematical Problem Solving at Different Ages." *Memory & Cognition* 32 (4): 648–661.
Thomas, W. P., and V. P. Collier. 2002. *A National Study of School Effectiveness for Language Minority Students' Long-Term Academic Achievement*. SantaCruz, CA: Center for Research on Education, Diversity and Excellence, University of California-Sanat Cruz.
Waters, N. E., S. F. Ahmed, S. Tang, F. J. Morrison, and P. E. Davis-Kean. 2021. "Pathways from Socioeconomic Status to Early Academic Achievement: The Role of Specific Executive Functions." *Early Childhood Research Quarterly* 54: 321–331.
Watts, T. W., G. J. Duncan, R. S. Siegler, and P. E. Davis-Kean. 2014. "What's Past is Prologue: Relations Between Early Mathematics Knowledge and High School Achievement." *Educational Researcher* 43 (7): 352–360.
Watzinger-Tharp, J., K. Swenson, and Z. Mayne. 2018. "Academic Achievement of Students in Dual Language Immersion." *International Journal of Bilingual Education and Bilingualism* 21 (8): 913–928.
Witt, M. 2011. "Mathematics and Transition." In *Bridging the Transition from Primary to Secondary School*, edited by A. Howe and V. Richards, 100–110. Abingdon: Routledge.
Yim, O., and E. Bialystok. 2012. "Degree of Conversational Code-Switching Enhances Verbal Task Switching in Cantonese–English Bilinguals." *Bilingualism: Language and Cognition* 15 (4): 873–883.
Zhang, D., C. F. Chin, and L. Li. 2017. "Metalinguistic Awareness in Bilingual Children's Word Reading: A Cross-Lagged Panel Study on Cross-Linguistic Transfer Facilitation." *Applied Psycholinguistics* 38 (2): 395–426.
Zinke, K., M. Zeintl, N. S. Rose, J. Putzmann, A. Pydde, and M. Kliegel. 2014. "Working Memory Training and Transfer in Older Adults: Effects of age, Baseline Performance, and Training Gains." *Developmental Psychology* 50 (1): 304.