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SPECIAL ISSUE ARTICLE

Interactions between levels of attention ability and levels of bilingualism in children's executive functioning

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Abstract

Attention difficulty is associated with poor performance on executive functioning (EF) tasks, yet EF is enhanced in bilingual children. However, no research to date has investigated the possible interaction between bilingualism and attention ability in children to determine the consequences for EF when both are present. We assessed a sample of typically developing children who were 8 to 11 years old for their ability in attention control and level of bilingualism on the basis of questionnaires completed by parents and teachers. Children performed three tasks requiring aspects of EF: stop signal task (inhibition), flanker task (interference control), and frogs matrices task (spatial working memory). Results from hierarchical regressions confirmed that both attention ability and bilingualism contributed to performance on the EF tasks. Where interaction effects were significant, they showed that attention ability was a stronger predictor for an inhibition task, namely stop signal, and bilingualism a stronger predictor for an interference task, namely flanker. Furthermore, these results allow us to discuss the relation between EF and attention ability.

Research highlights

- This project is the first to investigate the interaction between bilingualism and attention ability on children's executive functioning (EF).
- Both bilingualism and attention ability were considered on a continuum.
- Consistent with previous literature, poor attention was associated with poorer EF and greater degree of bilingualism was associated with better EF performance across all tasks.
- Interactions showed that each of bilingualism and attention ability is primary for different EF tasks.

Introduction

Executive functioning (EF) is the set of cognitive processes required to solve novel problems and accomplish a desired goal (Elliott, 2003). In an influential model of EF, Mikaye and colleagues identified the relevant component processes to be inhibition, shifting, and updating or working memory (Miyake, Friedman, Emerson, Witzki, Howerter *et al*., 2000) and argued that these components are both unique and overlapping (Miyake & Friedman, 2012). Other conceptions of EF similarly include the identification of subprocesses but differ in their structure (e.g. Shallice, Burgess & Robertson, 1996) and other models eschew components altogether and describe a continuum of effortfulness or attention (e.g. Engle, Laughlin, Tuholski & Conway, 1999). In the present study, we assume that specific tasks entail different aspects of EF or emphasize different levels of EF, making the construct at least in part a composite of subprocesses without adhering to a particular model. Regardless of its theoretical structure, however, performance on EF tasks is strongly correlated with academic achievement throughout the school years into adolescence (Best, Miller & Naglieri, 2011; Bull, Espy & Wiebe, 2008) and academic success predicts long-term health and well-being (Duncan, Ziol-Guest &

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Kalil, 2010). Thus, understanding the factors that promote or hinder the development of EF in children will inform efforts to foster achievement, health, and well-being in later development.

To this end, children's EF ability has been shown to be influenced by a number of factors and experiences. Specifically, bilingual competence has been demonstrated to promote EF development (see Barac, Bialystok, Castro & Sanchez, 2014, for review), whereas poor attentional abilities have been shown to be associated with lower EF performance (see Willcutt, Doyle, Nigg, Faraone & Pennington, 2005, for review). These competencies, therefore, pull children's EF development in opposite directions. No study to date has examined these factors together to determine the outcome of their joint presence. The present study considered both bilingualism and attention ability as continuous dimensions to investigate their role in predicting EF performance. Our main purpose was to determine whether each factor would produce the main effects on EF outcomes that is generally reported in the literature and whether they would interact in their influence on performance in a sample of typically developing children.

Attentional abilities and executive functions

In their seminal work, Posner and Petersen (1990, 2012) argued that multiple systems of attention (i.e. orienting, alerting, and executive) are responsible for the coordination of EF to achieve a goal. Therefore, an efficient attention system, or high level of attention ability, is imperative for effective EF in children. However, inherent in this view is the notion that EF and attention are not independent because attention is part of EF itself (for example, 'shifting' entails shifting of attention), a point to which we return in the Discussion. Thus, determining how these constructs are to be measured is crucial to interpreting their relationship.

Attention ability naturally varies across individuals, and children who exhibit severe difficulties with attention may be characterized clinically as displaying Attention Deficit Hyperactivity Disorder (ADHD). The symptoms of ADHD include ratings of inattention, hyperactivity and impulsivity, and children with a clinical diagnosis based on such symptoms constitute 5.9% to 7.1% of the overall population (Willcutt, 2012). Ratings of these symptoms have been found to vary on a continuum, with children at the low end meeting criteria for ADHD (Lubke, Hudziak, Derks, Van Bijsterveldt & Boomsma, 2009). Moreover, typically developing children display similar associations between attentional difficulties, EF, and outcomes, such as academic achievement (Hart, Petrill, Willcutt, Thompson, Schatschneider *et al*., 2010; Lambek, Tannock, Daslgaard, Trillingsgaard, Damm *et al*., 2011; Thorell, 2007). This association between ADHD symptoms or attentional difficulties and EF deficits has led researchers to argue for an EF theory of ADHD in which either a specific EF impairment (such as inhibition) or various EF deficits in combination contribute to the presentation of ADHD symptoms and diagnosis (Barkley, 2006; Sonuga-Barke, 2002, 2003, 2005). This theory is supported by an extensive literature demonstrating that children with ADHD have difficulty on measures of inhibition, working memory, and interference control (see Willcutt *et al*., 2005, for review). Furthermore, the poor performance of children with clinical ADHD on EF tasks has been linked to poor academic achievement in later childhood, adolescence, and adulthood, in both boys and girls (Biederman, Petty, Doyle, Spencer, Henderson *et al*., 2008; Miller & Hinshaw, 2010; Miller, Nevado-Montenegro & Hinshaw, 2012).

One task that has been particularly well studied in children with ADHD or attentional difficulties is the stop signal task (Logan, 1994), a measure of response inhibition. The task consists of two types of trials: go trials in which the participant completes an action when a stimulus is presented, and stop trials in which the participant is presented a cue indicating to refrain from completing the action. Children with ADHD require more time to stop the response and display different neural patterns during the task than controls (see Alderson, Rapport & Kofler, 2007, for review). Using ERP, Senderecka and colleagues (2012) found that the amplitude of the P3 component during successful stop trials was reduced in children with ADHD relative to controls. P3 amplitude for successful stop trials is considered to reflect monitoring of the inhibitory process, so the lower P3 amplitude was interpreted as a reflection of weak monitoring, an index of poor EF (Senderecka, Grabowska, Szewczyk, Gerc & Chmylak, 2012).

Another aspect of EF is interference control, the ability to avoid attending to misleading alternatives. Unlike response inhibition in which an action must be suppressed, interference control requires resolving the conflict from competing cues and suppressing attention to distraction. A prototypical measure of interference control is the flanker task (Eriksen & Eriksen, 1974) in which the participant is shown a line of five arrows and is asked to indicate the direction in which the middle arrow is pointing as quickly as possible. The task includes congruent trials, in which the surrounding arrows point in the same direction as the middle target arrow, and incongruent trials, in which the surrounding arrows point in the opposite direction. The increased difficulty in responding to the incongruent trials is reflected in: (a) longer reaction time (RT) than is found for congruent trials, a difference called the flanker effect, and (b) more errors. In their review of the literature, Mullane, Corkum, Klein and McLaughlin (2009) found that children with ADHD made more errors and displayed a larger flanker effect than controls, indicating weaker interference control than children who did not have attention deficits.

Finally, children with ADHD also attain poorer performance on measures of working memory than typically developing children. Martinussen, Hayden, Hogg-Johnson and Tannock (2005) conducted a meta-analysis of 26 studies and demonstrated that children with ADHD performed more poorly on spatial and verbal working memory tasks than controls (effect sizes ranged from 0.43 to 1.06). Overall, therefore, children with clinical diagnoses of ADHD perform more poorly than typically developing children on tasks of response inhibition, interference control, and working memory. ADHD, however, is one end of a continuum along which children vary in their level of attention ability. A more detailed approach to understanding these issues would be to examine the relation between variations in attention ability and EF in typically developing children.

Bilingualism and executive functions

In contrast to the poor EF performance observed in children with ADHD who have low attention abilities, the demands of the bilingual experience generally improve EF performance in children (see Barac *et al*., 2014, for review and Adesope, Lavin, Thompson & Ungerleider, 2010, for meta-analysis; for a contrary view see Dunabeitia, Hernandez, Anton, Macizo, Estevez *et al*., 2014; Gathercole, Thomas, Kennedy, Prys, Young *et al*., 2014). Although the mechanism through which bilingualism improves EF is not completely understood, it is generally accepted that the experience of monitoring attention to two jointly activated languages and avoiding interference from the non-target language over time leads to the observed improvements (Blumenfeld & Marian, 2007; Kroll, Bobb & Hoshino, 2014; Kroll & de Groot, 1997; Rodriguez-Fornells, Rotte, Heinze, Nosselt & Munte, 2002; Thierry & Wu, 2007). There is substantial evidence that both languages are active to some extent in bilingual language processing (Francis, 1999; Grainger, 1993; Kroll, Dussias, Bogulski & Valdes-Kroff, 2012; Marian & Spivey, 2003), creating the need to resolve competition from two language representations. Moreover, in a meta-analysis of 10 fMRI studies in which bilinguals performed a task that required them to switch between languages, the network that was activated during language switches was the domain-general EF network (Luk, Green, Abutalebi & Grady, 2012), supporting the interpretation that there is overlap in the attention processes used to control attention to languages and those used to control attention to nonverbal stimuli. The enhancement of EF in bilinguals has been found across the lifespan using a variety of tasks, particularly those requiring inhibition, working memory, and interference control (for review see Bialystok, Craik, Green & Gollan, 2009).

Evidence for the positive effect of bilingualism on EF has been reported using various tasks, although the individual components of EF involved in these tasks are not always clearly separable (see Kroll & Bialystok, 2013, for discussion). For example, evidence for better performance by bilinguals has been reported for such tasks as the Simon task (Lu & Proctor, 1995) and the flanker task (described above), both requiring participants to ignore irrelevant stimuli (inhibition) while shifting between congruent and incongruent trials (Carlson & Meltzoff, 2008; Kapa & Colombo, 2013; Martin-Rhee & Bialystok, 2008; Poarch & van Hell, 2012; Yang, Yang & Lust, 2011).

There is also some evidence showing better bilingual performance on working memory tasks, but these effects are less clear. Morales, Calvo and Bialystok (2013) found that bilingual children outperformed monolingual children on a spatial working memory task, the frog matrices task, which required participants to recall the sequence of hops a frog took between ponds that were arranged in a 3×3 grid. Studies using verbal working memory tasks have not shown such an advantage (Bialystok & Feng, 2009; Engel de Abreu, 2011), but bilinguals generally perform less well than monolinguals on verbal tasks (Bialystok, Luk, Peets & Yang, 2010). In studies of adults and older adults, bilinguals in both age groups outperformed monolinguals on working memory tasks that were nonverbal and involved a substantial amount of control but not on tasks that used verbal materials (Bialystok, Poarch, Luo & Craik, 2014; Luo, Craik, Moreno & Bialystok, 2013).

In sum, both attention difficulties and bilingualism have a significant impact on the development of EF but they operate in opposite directions: Whereas EF performance is compromised in individuals with lower attention abilities, it is enhanced in bilingualism. Given the importance of EF for long-term outcomes, it is crucial to understand the factors that affect its development. However, no research to date has investigated how these factors interact in children: Does bilingualism mitigate or exacerbate the effects of poor attention on EF development?

Research on both factors has generally involved comparing categorical groups (monolinguals versus bilinguals, children with or without ADHD), but both factors vary naturally along a continuum in a typical population. Researchers comparing the trajectory of children with ADHD have found that those who continue to display symptoms of ADHD in adolescence ('persisters') present with different impairments on EF tasks from children that no longer display symptoms ('remitters'; Halperin, Trampush, Miller, Marks & Newcorn, 2008), suggesting a more continuous than categorical description. In a longitudinal study following preschoolers, it was found that lower ratings of attention ability (or more ADHD symptoms) predicted lower EF performance one year later (Rajendran, Rindskopf, O'Neill, Marks, Nomura *et al*., 2013). Similarly, bilingualism is more continuous than categorical (Luk & Bialystok, 2013), and children's degree of bilingual experience has been found to be related to the degree of EF outcome (Bialystok, 1988; Bialystok & Barac, 2012; Crivello, Kuzyk, Rodrigues, Friend, Zesiger *et al*., 2016; Kalashnikova & Mattock 2014; Kapa & Colombo, 2013; Luk, De Sa & Bialystok, 2011). Thus, understanding the potential interaction between these experiences requires considering the full range of variability in both attention ability and bilingualism to evaluate their joint effect on EF performance.

Two studies to date have used a categorical approach to address the potential interaction between bilingualism and attention ability on EF in an adult population. In the first, Mor, Yitzhaki-Amsalem and Prior (2015) administered EF tasks to young adults from a university population who had been diagnosed with clinical ADHD or not and whom they classified as monolingual or bilingual. Their results showed the poorest performance among those who were classified as bilingual with ADHD. However, none of their participants was monolingual; the mean score in the 'monolingual' group on a university entrance test was 126.6 for Hebrew and 125.1 for English. Similarly, their bilingual group was actually trilingual in that they also spoke a third language, generally Russian, possibly creating further group differences. Moreover, the participants did not range in their attention ability but were considered as clinically impaired or not. In the second, Bialystok, Hawrylewicz, Wiseheart and Toplak (in press) compared groups for their performance on a flanker task and a stop signal task. In the flanker task there were independent effects of bilingualism and ADHD status, with bilinguals and non-ADHD participants showing smaller cost in RT to perform the conflict trials. In the stop signal task, in contrast, the bilinguals with ADHD were significantly more impaired than were participants in the other groups, consistent with the findings by Mor *et al*. (2015) for trilinguals. Thus, the essential questions remain unanswered.

The purpose of the present study was to investigate the interaction of bilingualism and attention abilities on EF in typically developing children. Both bilingualism and attention abilities were assessed on continua to capture variation in the population. English language proficiency and nonverbal intelligence were assessed to control for these abilities in regression analyses. Children performed tasks that relied primarily on inhibition (stop signal task), interference control (flanker task), or spatial working memory (frog matrices task) to assess a range of EF ability. It was expected that lower attention abilities would be related to poorer performance on the EF tasks and that bilingualism would be related to better performance, but the extent to which performance would be calibrated to these experiences or affected by their interaction was unknown. Bilingualism was quantified on the basis of a questionnaire regarding children's language experience and use, while attention ability was quantified on the basis of questionnaires regarding behaviors symptomatic of ADHD, although no child in the study had obtained a clinical diagnosis of this condition.

Method

Participants

Participants were 208 children ($n_{\text{males}} = 99$; $n_{\text{females}} = 109$) and their parents/guardians and teachers recruited from six public schools in a large diverse metropolitan area. Children (8–11 years; $M = 9.21$; $SD = .93$) were given packages to take home that included a consent form and two questionnaires, namely, the Language and Social Background Questionnaire (LSBQ) and the Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (SWAN). Children who returned completed questionnaires and consent forms were included in the study. The majority of the children were born in Canada (72.1%), with 11 children born in India (5.3%), 6 children born in China (2.9%), 5 children born in the Philippines (2.4%), and 36 children (17.3%) being born in 23 different countries. School instruction was in English for all children. There were 33 different non-English languages used in the homes. Maternal education was assessed as a proxy for socioeconomic status (SES) and was well distributed in the sample: 13.0% indicated that they did not complete high school, 15.4% graduated from high school, 24.0% completed some college, 20.0% obtained a bachelor's degree, and 26.4% obtained a graduate or professional degree.

Procedure

Children were tested individually in a quiet space in their school in two sessions separated by approximately one to two weeks. Tasks were presented in a fixed order: Session 1 included the frog matrices task and the Peabody Picture Vocabulary Test-Third edition (PPVT-III; Dunn & Dunn, 1997); Session 2 included the stop signal task, Raven's Progressive Matrices (Raven, 2003), and the flanker task. Each session took approximately 25 minutes to complete. A standardized *z*-score of the raw scores (not corrected for age) from both the PPVT-III and Raven's were calculated and summed to create a composite raw score for intellectual ability. All tasks were administered using a 15-inch KEYTEC Magic Touch computer.

Tasks and instruments

Language and Social Background Questionnaire (LSBQ; Luk & Bialystok, 2013)

The LSBQ is a parent-report questionnaire which includes demographic information (e.g. socioeconomic status) as well as items related to language use in the family environment. To assess the child's level of bilingualism, responses to 31 items were summed across such questions as the language used by the child when speaking to family members (e.g. mother, father, etc.), the language used by family members when speaking to the child, the language used by the parent when speaking to other family members, and the language used for various media (e.g. internet, reading, television, etc.). Each item was rated on a 7-point Likert scale, ranging from 'All in English' (1) to 'All in other language' (7). Therefore, higher scores represent less English use in the home and thus indicate that children are more bilingual since their education and most activities outside the home are conducted in English. The bilingualism scale had excellent internal consistency ($\alpha = .98$). The mean item total was used as the bilingualism variable.

Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale (SWAN; Swanson, Schuck, Mann, Carlson, Hartman *et al.*, 2001)

The SWAN questionnaire is a research measure used to assess attention ability and was completed by the child's parent or guardian and the child's teacher. The SWAN includes 18 items, each mapping onto the symptoms indicated for a diagnosis of ADHD as described in the DSM-5 (American Psychiatric Association, 2013). Thus, the SWAN assesses symptoms related to inattention (nine items, e.g. 'Stays focused on tasks and activities'), hyperactivity (six items, e.g. 'Can sit without constant fidgeting or squirming'), and impulsivity (three items, e.g. 'Easily waits turn, such as standing in line-ups'). Unlike other clinical rating scales, the SWAN uses a strength-based approach with each item being positively worded. The original wording of the items was slightly changed to improve ease of reading and decrease word difficulty (e.g. 'Sustains attention on tasks or play activities' was changed to 'Stays focused on tasks and activities'). The child's guardian and teacher rated the child's behavior for each item using a 7-point Likert scale ranging from 'Far below average' (1) to 'Far above average' (7). The SWAN has been shown to have excellent internal consistency and reliability (Lakes, Swanson & Riggs, 2012; Young, Levy, Martin & Hay 2009). Consistent with previous research, in the current study the internal consistency was high (Parent $\alpha = .96$; Teacher $\alpha = .98$). A higher score indicates better attentional abilities.

Stop signal task

The stop signal task was adapted from Logan and colleagues and used as a measure of inhibition (Logan & Cowan, 1984; Williams, Ponessee, Schachar, Logan & Tannock, 1999). The child was instructed to use two computer mice, one located on each side of the laptop, to indicate whether the stimulus shown on the screen was an X (press left button) or an O (press right button). A fixation point (+) preceded each trial and was presented for 500 ms, followed by the letter that was presented for 1000 ms. For the stop signal trials, a tone followed the presentation of the letter indicating that the child was to refrain from pressing either mouse button. The stop signals occurred on 25% of the trials in each block (8 out of 32 trials). The initial duration between the presentation of the go stimuli and the stop signal, called the stop signal delay, was 250 ms and was adjusted dynamically by 50 ms depending on whether the child responded correctly to the previous stop trial. For example, if the child inhibited the response on a stop trial, then the stop signal delay was increased by 50 ms making it more difficult to stop on the subsequent stop trial (Logan, Schachar & Tannock, 1997; Shuster & Toplak, 2009). An equal number of Xs and Os were presented during each block for both the go and stop trials. The order of trials was randomized for each participant. The variable of interest was the stop signal reaction time (SSRT), defined as the mean signal delay subtracted from the mean go trial reaction time (ms); shorter SSRT indicates better performance. As in previous research with this task, the average SSRT from the final four experimental blocks was used as the dependent variable. The initial block was not included in the analyses to remove the trials in which the child was still learning the task. The child was encouraged to respond as quickly as possible and a practice block was completed before the five experimental blocks.

Flanker task

This task was used as an indicator of interference control (Eriksen & Eriksen, 1974). Participants were asked to indicate the direction in which a red target chevron presented on the computer screen was pointing. The task consisted of five blocks: Baseline, Neutral, Mixed Incongruent/Congruent, Neutral, and Baseline. Each block began with practice items to ensure the child understood the requirements of the task. For the practice trials, the child was provided feedback in the form of a green happy face or red sad face.

In baseline trials, the red target chevron was presented alone in the center of the screen. In the other conditions, it was flanked by four other items: In neutral trials, it was surrounded by black diamonds, in congruent trials by four black chevrons pointing in the same direction, and in incongruent trials by four black chevrons pointing in the opposite direction. For these three conditions, the red target chevron was in either the second, third, or fourth position in the array. Each test trial began with a fixation presented for 250 ms, followed by the stimulus display for 2000 ms. There were a total of 48 trials baseline trials (24 per Baseline Block), 48 neutral trials (24 per Neutral Block), and 48 mixed trials consisting of 24 congruent and 24 incongruent trials. The variables of interest were accuracy and reaction time to congruent and incongruent trials in the mixed block and the reaction time differences between congruent and neutral trials, incongruent and neutral trials, and incongruent and congruent trials (flanker effect). These variables were selected because of their EF demands. Faster RTs and higher accuracy scores indicated better interference control.

Frog matrices task

This task was used as a measure of spatial working memory, following the methodology described by Morales *et al.* (2013). The child was shown a 3×3 matrix on the computer screen and was told that each of the nine cells represented a pond in which the frog could hop, and that the child would need to remember which ponds had previously contained frogs. Children responded by pressing on the touch screen to select a pond. The pond then changed color to indicate that it had been selected. Children completed three conditions of the task in a fixed order. Each condition was preceded by example items and practice trials with feedback. Each condition began with the child being asked to recall two frogs or locations, and increased after every two trials to a maximum of six frogs or locations.

In the first condition, simultaneous, all the frogs appeared in the matrix at the same time. The display was shown for 2000 ms followed by a 2000 ms delay during which empty ponds were presented. Then, a ‘ding’ sounded indicating to the child to respond. Children touched the ponds in any order to show where the frogs had appeared. In the second, sequential, and third, operational, conditions, the frogs were presented individually for 1000 ms each, and the ‘ding’ occurred after the final frog of the sequence was presented. The sequential condition required the child to recall both the positions and the exact order in which the frogs were presented. In the operational condition the child was asked to indicate the ponds using a predetermined order (see Figure 1). This order was explicitly indicated in the instructions and each pond was connected by ‘bridges’ to help remind the child of the order of responses required. Thus children had to mentally reorder the sequence of ponds. For task consistency, the ‘bridges’ between ponds remained visible for all conditions.

Scores for the simultaneous condition were calculated as the number of correct locations recalled (maximum score: 40). For the sequential and operational conditions, scores were calculated separately for the correct location and the correct order. Thus, a child was given one point for accuracy of the location of the frog, and one point for providing the location in the correct order in the sequence, for a maximum of 80 points per condition. For example, if the correct sequence was 2 – 3 – 8, and the child selected 3 – 2 – 8, the child would receive 3 points for providing the correct locations (2, 3, and 8), and an additional point for providing one location in the correct order (i.e. pond 8), for a total of 4 points. Higher scores on the frog matrices task indicated better spatial working memory performance.

Analysis plan

Hierarchical linear regressions were conducted using SPSS 23. Mean attention and bilingualism scores were centered so that each variable had a mean of 0. Interaction terms were computed by multiplying centered attention with centered bilingualism scores. Centered maternal level of education (used as a proxy for socioeconomic status), centered age, and a centered composite of PPVT-III and Raven’s raw scores were

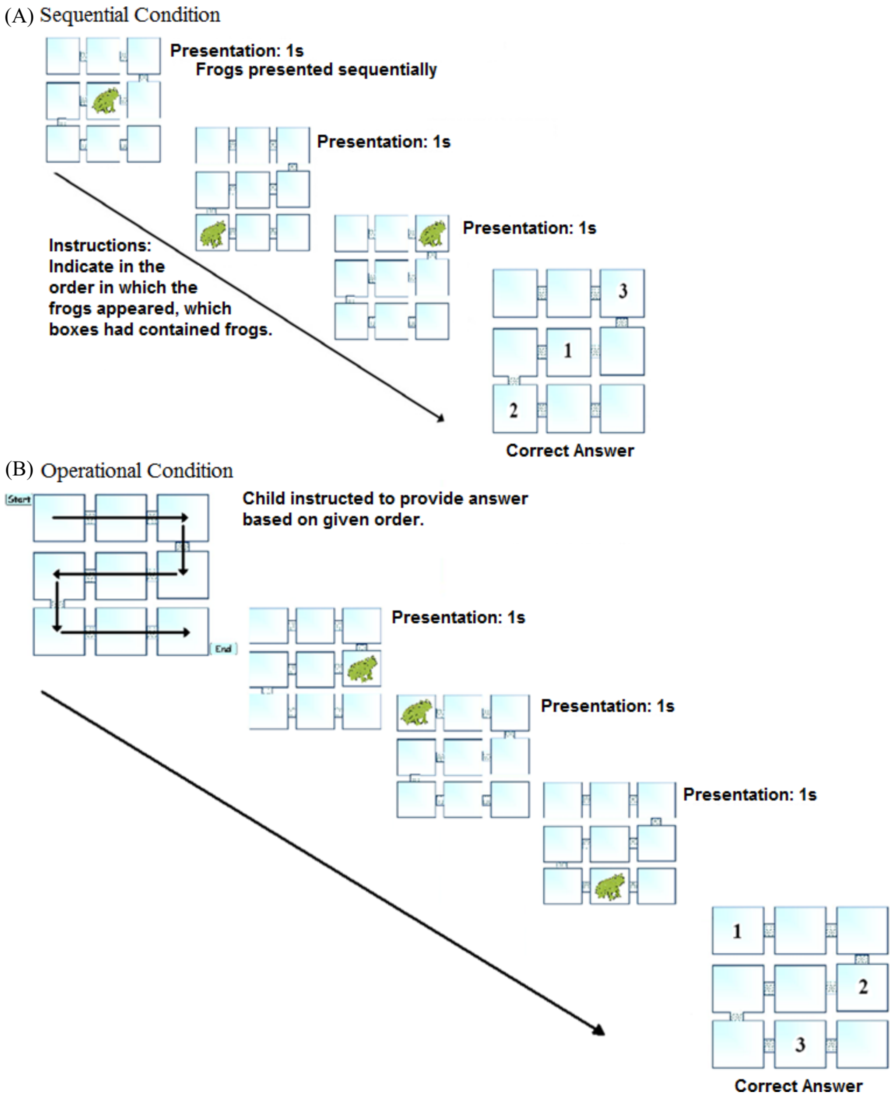

Figure 1 *Sample items from the sequential (a) and the operational (b) condition from the frog matrices task.*

entered at the first step to control for their variance. Centered mean bilingualism and centered mean attention scores were each entered as a second step separately. Each variable was entered individually to determine the unique variance it explained. The interaction term (mean bilingualism × mean attention) was entered at the third step. Regression models were conducted separately for each of the stop signal task, the flanker task, and the Frog matrices task. Interaction™ software was used to deconstruct significant interactions (Sorper, 2011).

Using this procedure, two sets of hierarchical linear regressions were conducted for each task. The first set, reported as 'whole sample', included all participants to determine whether there were effects from the two predictors (bilingualism and attention) and whether they interacted. For this first regression, the bilingualism variable was bimodal due to a large portion of monolinguals in the sample so the analysis was treated as a categorical distinction between monolingual and bilingual. Therefore, bilingualism was entered as a dichotomous variable, in which participants with a score of 1.5 or greater on the LSBQ were considered to be bilingual and those with less were coded as monolingual. The second set of regressions, reported as 'bilingual sample', included only participants with a mean bilingualism score greater than 1.5 (n = 132), excluding children who were monolingual to determine whether degree of bilingualism affected performance. For this second set of regressions, bilingualism was entered as a continuous variable.

Results

Outlier analysis

Twenty-five of the 208 participants were removed from analyses because of errors in the completion of the questionnaires measuring the key predictors of bilingualism (n = 8) or attention ability (n = 1), or standard scores below 70 on the PPVT-III (n = 7) or Raven's (n = 9). Thus, the final analyses included 183 children.

From this final sample, some participants were removed from the analyses of specific tasks. On the stop signal task, participants were removed if their probability of stopping was below 20.0% or above 80.0% (n = 9) or if the average SSRT, or SSRT on a single block of trials, was below 50 ms (n = 6; Logan *et al.*, 1997; Shuster & Toplak, 2009). No participant was removed for low accuracy. On the flanker task, participants were excluded from analyses if accuracy was below 75% (n = 13). On the frog matrices task, participants were removed if their combined score on the sequential and operational conditions was 2.5 standard deviations below the mean (n = 6; Rousseeuw & Croux, 1993). These trimming procedures followed those used in previous research with these tasks. Importantly, data trimming reduces the likelihood of finding significant differences between groups, so application of such procedures constitutes a conservative approach to data analysis (Zhou & Krott, in press).

Descriptive statistics

Descriptive statistics for background measures and task performance are presented in Table 1. The parent and teacher SWAN scores were strongly correlated, r = .61, $p < .001$, so for participants with both parent and teacher ratings, scores were standardized using z-scores and a composite was created by taking the average of the two scores (n = 70). For the remaining participants (n = 113) who did not have teacher ratings, only the standardized parent/guardian scores were used. Key predictor variables for both bilingualism and attention demonstrate the natural variation expected from a typically developing sample of children living in a diverse community. Correlations between all independent variables and dependent variables are presented in Table 2.

Stop signal task

Results for the whole sample regression analysis in which bilingualism is treated categorically are shown in Table 3a. Both bilingualism (R^2 = 5%, $p < .01$) and better attention ability (R^2 = 7%, $p < .01$) were significantly associated with better performance. The addition of the bilingualism × attention interaction term did not increase the variance explained by the model. Cognitive ability was a significant predictor, but neither age nor SES emerged as significant control variables.

The results of the model for the bilingual sample using a continuous measure of bilingualism are shown in Table 3b. Attention ability was again a significant predictor of performance (R^2 = 6%, $p < .01$), and the interaction of level of bilingualism and level of attention was also significant (R^2 = 4%, $p < .05$), indicating that the effect of each factor depended on the level of the other. The simple slopes for levels of bilingualism shown in Figure 2 (±2 standard deviations from the mean) were associated with improved SSRT as attention ability increased. By comparing the slopes, it was observed that bilingualism had relatively little influence on performance for children with low attention abilities but a larger impact for those who were more able to control attention. Note, however, that at all points along the continuum, bilingualism was associated with increased performance; it is the relative impact of bilingualism that changes with level of attention.

Flanker task

Performance data are presented in Table 1 and results for the whole sample regression are shown in Table 4a.

Table 1 *Descriptive statistics for participants*

Variable	Mean (*SD*)
Control variables (N = 183):	
PPVT-III	101.02 (15.13)
Raven's Matrices	97.21 (16.41)
Predictors (N = 183):	
Attention ability Parent SWAN	4.87 (1.08)
Attention ability Teacher SWAN	4.75 (1.42)
Bilingualism LSBQ	2.87 (1.43)
Outcome variables:	
Stop Signal Task (n = 168)	
Stop Signal RT (SSRT)	311 (106)
Flanker Task (n = 170)	
Baseline Mean Accuracy %	94.25 (6.46)
Baseline Mean RT	513 (87)
Neutral Mean Accuracy %	93.15 (6.96)
Neutral Mean RT	645 (99)
Mixed Block Mean Accuracy %	92.73 (6.23)
Mixed Block Mean RT	728 (110)
Frogs Matrix Task (n = 177)	
Simultaneous Accuracy %	96.36 (4.33)
Sequential Accuracy %	85.02 (7.70)
Operations Accuracy %	80.40 (12.13)

Note: PPVT – Peabody Picture Vocabulary Test; SWAN – Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale; LSBQ – Language and Social Background Questionnaire.

Table 2 *Correlations (r-value) between independent and dependent variables*

	Dependent variables					
Predictors	Stop signal task	Flanker mixed block accuracy	Flanker mixed block RT	Frogs – simultaneous accuracy	Frogs – sequential accuracy	Frogs – operational accuracy
Bilingualism	−.15*	.18*	.07	.15*	.13	.06
Attention	−.26***	.26***	−.12	.18*	.02	.10
Age	−.13	−.07	−.44***	.25**	.26***	.34***
SES	−.12	.16*	.05	.10	.03	.07
Raven's	−.22**	.31***	−.16*	.33***	.45***	.56***
PPVT-III	−.16*	.05	−.28***	.21**	.20*	.32***

Note 1: $*p < .05$; $**p < .01$; $***p < .001$.
Note 2: PPVT – Peabody Picture Vocabulary Test; Frogs – Frog Matrices Task.

Table 3 *Factors predicting performance on stop signal task*

Predictor	ΔR^2	B	t
(a) Regression model examining whole sample			
Step 1	.08		
Age		−.11	−1.19
Maternal Education		−.04	−.46
Cognitive Ability Composite		−.20	−2.11*
Step 2a			
Bilingualism	.05	−.21	−2.63**
Step 2b			
Attention abilities	.07	−.26	−3.25**
Step 3			
Bilingualism × Attention abilities	.00	−.15	−.56
Total R^2	.18[a]		
n	142		
(b) Regression model examining the bilingual sample			
Step 1	.06		
Age		−.10	−.99
Maternal Education		−.10	−.98
Cognitive Ability Composite		−.15	−1.47
Step 2a			
Bilingualism	.01	−.09	−.99
Step 2b			
Attention abilities	.06	−.26	−2.82**
Step 3			
Bilingualism × Attention abilities	.04	−.66	−2.28*
Total R^2	.16[a]		
n	120		

Note 1: All variables were centered.
Note 2: Cognitive Ability Composite based on sum of z-score standardized scores from the PPVT-III and Raven's.
[a]Total R^2 reported based on bilingualism and attention ability entered simultaneously.
$*p < .05$, $**p < .01$

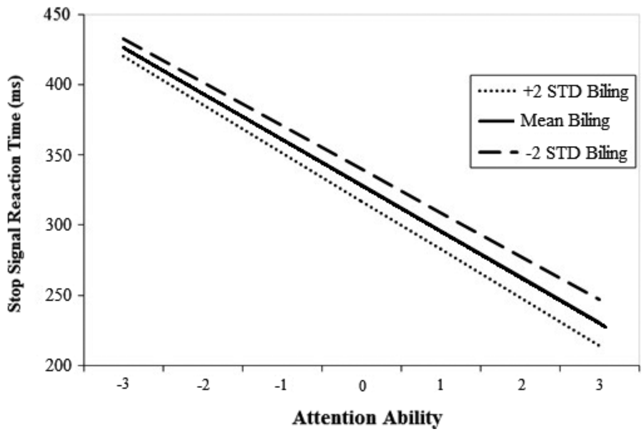

Figure 2 *Association between attention ability and stop signal reaction time as a function of level of bilingualism for participants with some bilingual experience.*

None of the control variables (cognitive ability, SES, or age) was significantly associated with accuracy in the mixed block. Attention ability (R^2 = 3%, $p < .05$) emerged as a significant predictor of accuracy, but bilingualism was not related to performance. The addition of the bilingualism × attention interaction term to the model did not increase the variance explained. In a separate regression analysis using mixed block RT as the dependent variable, only age and cognitive ability emerged as significant predictors, with no contribution from attention ability, bilingualism or their interaction. Furthermore, the reaction time difference score between the congruent and neutral trials, incongruent and neutral trials, and the flanker effect (incongruent and congruent trials) yielded no significant predictors.

In the bilingual sample regression on mixed block accuracy, shown in Table 4b, attention ability (R^2 = 7%, $p < .01$) remained a significant predictor, and degree of bilingualism (R^2 = 4%, $p < .05$) emerged as significant as well. Thus, for participants with some level of bilingualism, more experience using another language was associated with better accuracy. Importantly, the interaction term increased the amount of variance explained (R^2 = 3%, $p < .05$), indicating that the association between attention ability and accuracy depended on degree of bilingualism. The simple slopes for levels of bilingualism (±2 standard deviations from the mean) were all positive, reflecting improved accuracy as attention ability

Table 4 *Factors predicting accuracy on flanker incongruent and congruent trials*

Predictor	ΔR^2	B	t
(a) Regression model examining the whole sample			
Step 1	.02		
Age		−.05	−.53
Maternal Education		.07	.87
Cognitive Ability Composite		.11	1.19
Step 2a			
Bilingualism	.00	.05	.54
Step 2b			
Attention abilities	.03	.18	2.21*
Step 3			
Bilingualism × Attention abilities	.00	.12	.40
Total R^2	.06[a]		
n	142		
(b) Regression model examining the bilingual sample			
Step 1	.08		
Age		−.10	−1.02
Maternal Education		.15	1.49
Cognitive Ability Composite		.19	1.91
Step 2a			
Bilingualism	.04	.21	2.36*
Step 2b			
Attention abilities	.07	.27	3.03**
Step 3			
Bilingualism × Attention abilities	.03	−.58	−2.14*
Total R^2	.19[a]		
n	121		

Note 1: All variables were centered.
Note 2: Cognitive Ability Composite based on sum of z-score standardized scores from the PPVT-III and Raven's.
[a]Total R^2 reported based on bilingualism and attention ability entered simultaneously.
$*p < .05$; $**p < .01$.

increased. Comparing children at the extremes of attention ability, children low in attention ability experienced a greater boost in performance from bilingualism than did children with higher attention scores (see Figure 3). Again, children who were more bilingual were more accurate than those who were less bilingual at all points along the attention scale. As in the analyses of accuracy, reaction time measures (i.e. mixed block RT, and difference score between the congruent and neutral trials, incongruent and neutral trials, and the flanker effect) were related only to age and cognitive ability.

Frog matrices task

Children performed at ceiling on the simultaneous condition of the frog matrices task, so no further analyses were performed on this condition. The mean accuracy scores for the sequential and operational conditions, reported in Table 1, were correlated (r = .54, p < .001), so these scores were standardized using z-scores and then averaged, and this variable was used as the dependent variable in the regression analyses.

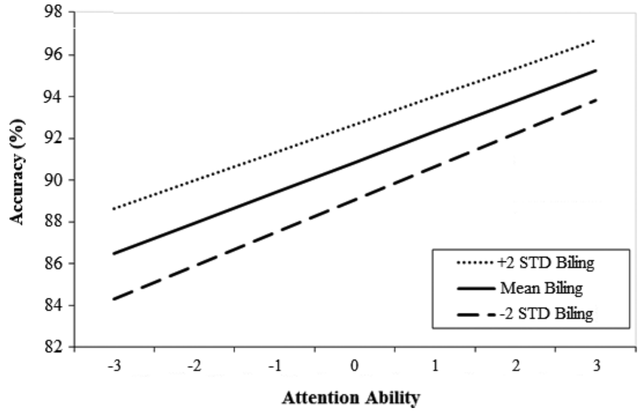

Figure 3 *Association between attention ability and accuracy on incongruent and congruent trials from the flanker task sas a function of level of bilingualism.*

Table 5 *Factors predicting performance on the frog matrices task*

Predictor	ΔR^2	B	t
(a) Regression model examining the whole sample			
Step 1	.35		
Age		.22	3.30**
Maternal Education		−.10	−1.44
Cognitive Ability Composite		.53	7.17***
Step 2a			
Bilingualism	.02	.14	2.23*
Step 2b			
Attention abilities	.00	.05	.83
Step 3			
Bilingualism × Attention abilities	.01	−.25	−.1.11
Total R^2	.37[a]		
n	155		
(b) Regression model examining the bilingual sample			
Step 1	.33		
Age		.16	2.03*
Maternal Education		−.17	−2.11*
Cognitive Ability Composite		.54	6.42***
Step 2a			
Bilingualism	.02	.16	2.13*
Step 2b			
Attention abilities	.00	−.04	−.52
Step 3			
Bilingualism × Attention abilities	.00	−.05	−.21
Total R^2	.36[a]		
n	129		

Note 1: All variables were centered.
Note 2: Cognitive Ability Composite based on sum of z-score standardized scores from the PPVT-III and Raven's.
[a]Total R^2 reported based on bilingualism and attention ability entered simultaneously.
$*p < .05$; $**p < .01$; $***p < .001$.

The results from the first regression examining the whole sample are shown in Table 5a. There was a significant contribution to performance from two control variables in which cognitive ability and age emerged as significant predictors (R^2 = 35%). Following that, bilingualism explained a significant proportion of the variance (R^2 = 2%, $p < .05$), but attention ability did not contribute significantly to performance. The addition of the interaction term did not increase the amount of variance explained.

The pattern was similar for the bilingual sample regression. The control variables (age, SES, and cognitive ability) were significant predictors of performance, and more bilingualism (R^2 = 2%, $p < .05$) again was associated with better performance, but neither attention ability nor the interaction term was significant (see Table 5b).

Discussion

Both level of bilingualism and attention ability were related to performance on three EF tasks in a group of typically developing children with varying backgrounds. Each of the tasks emphasized a different aspect of EF, and the results were somewhat different for each task. The stop signal task is considered to be a measure of response inhibition and is strongly associated with attention difficulty, including clinical impairment such as ADHD (Alderson *et al*., 2007). Here the results showed that both attention ability and level of bilingualism were important predictors, but attention ability took precedence. Thus, bilingualism provided a larger boost to performance for children with good attention ability and had less benefit for children with poorer attention ability. This finding is similar to that with adults in which bilingualism had a somewhat negative effect for those with an attention disorder performing a task based primarily on inhibitory control (Bialystok *et al*., in press). Nonetheless, in the present study bilingualism continued to predict a significant portion of the variance for children at all points on the attention continuum presumably because clinical deficits in attention were not included in the sample.

The flanker task is commonly used as a measure of EF in children and performance has been related to both attention ability (Mullane *et al*., 2009) and bilingualism (Kapa & Colombo, 2013; Poarch & van Hell, 2012; Yang *et al*., 2011). There was no systematic relation between these factors and reaction time, but accuracy scores were predicted by both attention ability and bilingualism, with a significant interaction between them for children who were bilingual. Unlike the results of the stop signal task where bilingualism was a greater benefit to children with higher attention ability, on this task the greater benefit of bilingualism was for children with poorer attention ability. Our interpretation is that limitations in attention ability are an obstacle to stop signal performance because attention is primary but such limitations are less of a barrier for flanker task performance, allowing the benefit of bilingualism to have a greater influence. Similarly, the study by Bialystok *et al*. (in press) showed no interaction between bilingualism and ADHD status for performance on a flanker task, with bilingualism improving performance for participants in both ADHD groups.

The measure of spatial working memory, the frog matrices task, was an untimed test in which children were required to hold information in mind over a delay and in some cases manipulate that information to conform to a rule. Previous research has shown that bilingual children perform this task more accurately than monolinguals (Morales *et al*., 2013), but there is little basis for predicting that typically developing children with poor attention abilities would be impaired. For clinical samples, it has been shown that working memory is poorer for children with ADHD (Martinussen *et al*., 2005), but it was not known how a non-clinical population who varies in attention abilities would perform this task. The results showed that only bilingualism was a significant predictor of performance and that being more bilingual was further associated with greater gains on this task. The absence of a significant association between attention ability and performance on this task could reflect two possibilities: poor memory performance may only be observable in children with severe attention difficulties (i.e. clinical ADHD populations), or the lack of a time limit and absence of an inhibition component may make the task accessible to all children irrespective of their level of attention ability.

The main conclusion is that both bilingualism and attention ability are important for determining EF performance in a typically developing population for whom values on these dimensions vary incrementally. Crucially, the precise nature of the effect of each factor and the interaction between them depends on the specific task demands. Thus, a task heavily dependent on attentional control (stop signal) is predicted primarily by attention ability and a task heavily dependent on working memory (frog matrix) is predicted primarily by bilingualism. The flanker task is somewhat between these extremes: it is a simple task that requires a range of EF processes including inhibition and shifting, and the contribution of attention ability and bilingualism was more equivalent in this case. The subtleties represented in this pattern of results help to understand why some studies that compare performance of two groups (e.g. monolingual vs. bilingual) performing simple tasks (e.g. flanker) fail to find significant differences in performance (e.g. Dunabeitia *et al*., 2014). These experiential factors interact in complex ways that depend on the nature of the task and the nature of the population.

Our results are different from those found by Mor *et al*. (2015) who reported additional EF burden for bilingual participants with clinical diagnoses of ADHD and Bialystok *et al.* (in press) who reported additional EF burden for bilingual participants with ADHD performing a stop signal task, but our study is quite different from those. Most obviously, our study investigated children (not adults) who were typically developing (not clinical) and who varied continuously on degree of bilingualism and degree of attention ability. Moreover, none of the participants in the Mor *et al.* study was monolingual, so the baseline comparisons in that study were substantially different from ours. Therefore, to our knowledge, our study is the first to investigate the contribution of bilingualism, attention ability and their interaction on the development of EF in a typically developing sample of children.

An important outcome of our results is the demonstration that both more bilingualism and better attention ability were associated with better performance, but that children with low attention abilities were not further impaired by being bilingual and bilingual children were not further impaired by poor attention. In other words, the interaction effects revealed the relative level of enhancement of bilingualism on EF performance as a function of attention ability but never indicated a reversal in which bilingualism or attention became a liability when it was combined with the other factor.

This pattern in which bilingualism neither compensates for nor exacerbates the effect of another risk factor is similar to results reported for the interaction of bilingualism and SES. Like poor attention ability, low SES is associated with poor EF performance. Calvo and Bialystok (2014) compared 175 6-year-old children who were classified as higher or lower SES and monolingual or bilingual performing several EF tasks and showed that bilingual children in both SES groups outperformed their monolingual counterparts and that higher SES children in both language groups outperformed their lower SES peers. Similar results were recently reported by Krizman, Skoe and Kraus (in press). Thus, each factor contributed uniquely to children's EF development with no evidence of compensation or further impairment. In contrast, results from both Mor *et al.* (2015) and Bialystok *et al.* (in press) show that actual impairment to attention in the form of clinical ADHD can not only block the potential enhancing effect of bilingualism but also reveal an additional burden.

Other support for the interpretation that bilingualism has only minimal interaction with other risk factors comes from a study of monolingual and Spanish-English bilingual children with autism spectrum disorders (Valicenti-McDermott, Tarshis, Schouls, Galdston, Hottinger *et al.*, 2013). The main challenge for these children is in the development of communication skills, and the results showed that there was no difference between the monolingual and bilingual children in the development of expressive or receptive language skills or in performance on cognitive tasks. Thus, bilingualism does not add to risk experienced by children in a variety of compromising situations.

These results allow us to revisit the relation between EF and attention ability, terms that are sometimes used interchangeably in the literature. The two uses of 'attention' in the present study are first as a description of a behavior that can signal potential cognitive problems if it reaches clinical levels of impairment, and second as a process required to perform tasks that fall under the umbrella of executive function. Evidence for the first is typically obtained through questionnaire report and diagnostic interviews, while evidence for the second is obtained through task performance. Our proposal is that these concepts are less distinct than they might seem; it may be that the relevant distinction between the 'components of EF' may be less in the qualitative type of ability they recruit (such as shifting or inhibiting) than in their quantitative reliance on attention. As an individual ability, this attention is distributed along a continuum, and as a requirement for task performance, it distinguishes between tasks on the basis of effortfulness. The broader claim is that ongoing life experience that provides constant conflict or complexity, such as bilingualism, enhances that attention system through practice (see Bialystok, 2015, for discussion).

In conclusion, the current study investigated the potential interaction of two factors known to impact EF development: bilingualism and attention abilities. The most important finding is that each of these factors alone exerts a strong influence on children's EF development throughout variations in the other factors, and interactions reveal more subtle relative levels of impact for each factor for different tasks. These results are powerful support for the role of bilingualism in children's EF development, a point made in previous literature, but extends those earlier results by demonstrating that bilingualism neither further impairs nor eradicates EF difficulties associated with poor attention ability. Given the fundamental importance of EF to children's development and future well-being, it is essential to understand how that development is best promoted. Bilingualism is clearly one such avenue.

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References

Adesope, O.O., Lavin, T., Thompson, T., & Ungerleider, C. (2010). A systematic review and meta-analysis of the cognitive correlates of bilingualism. *Review of Educational Research*, **80**, 207–245.

Alderson, R.M., Rapport, M.D., & Kofler, M.J. (2007). Attention-Deficit/Hyperactivity Disorder and behavioral inhibition: a meta-analytic review of the stop-signal paradigm. *Journal of Abnormal Child Psychology*, **35**, 745–758. doi:10.1007/s10802-007-9131-6

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th edn.). Arlington, VA: American Psychiatric Publishing.

Barac, R., Bialystok, E., Castro, D.C., & Sanchez, M. (2014). The cognitive development of young dual language learners: a critical review. *Early Childhood Research Quarterly*, **29**, 699–714.

Barkley, R.A. (Ed.) (2006). *Attention deficit hyperactivity disorder: A handbook for diagnosis and treatment* (3rd edn.). New York: Guilford.

Best, J.R., Miller, P.H., & Naglieri, J.A. (2011). Relations between executive functions and academic achievment from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, **21**, 327–336. doi:10.1016/j.lindif.2011.01.007

Bialystok, E. (1988). Levels of bilingualism and levels of linguistic awareness. *Developmental Psychology*, **24**, 560–567.

Bialystok, E. (2015). Bilingualism and the development of executive function: the role of attention. *Child Development Perspectives*, **9**, 117–121.

Bialystok, E., & Barac, R. (2012). Emerging bilingualism: dissociating advantages for metalinguistic awareness and executive control. *Cognition*, **122** (1), 67–73. doi:10.1016/j.cognition.2011.08.003

Bialystok, E., Craik, F., Green, D.W., & Gollan, T.H. (2009). Bilingual minds. *Psychological Science in the Public Interest*, **10**, 89–129. doi:10.1177/1529100610387084

Bialystok, E., & Feng, X. (2009). Language proficiency and executive control in proactive interference: evidence from monolingual and bilingual children and adults. *Brain and Language*, **109**, 93–100. doi:10.1016/j.bandl.2008.09.001

Bialystok, E., Hawrylewicz, K., Wiseheart, M., & Toplak, M. (in press). Interaction of bilingualism and Attention-Deficit/Hyperactivity disorder in young adults. *Bilingualism: Language and Cognition*.

Bialystok, E., Luk, G., Peets, K.F., & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Bilingualism: Language and Cognition*, **13**, 525–531. doi: 10.1017/S1366728909990423

Bialystok, E., Poarch, G., Luo, L., & Craik, F.I.M. (2014). Effects of bilingualism and aging on executive function and working memory. *Psychology and Aging*, **29**, 696–705. doi:10.1037/a0037254

Biederman, J., Petty, C.R., Doyle, A.E., Spencer, T., Henderson, C.S., et al. (2008). Stability of executive function deficits in girls with ADHD: a prospective longitudinal follow-up study into adolescence. *Developmental Neuropsychology*, **33**, 44–61. doi:10.1080/87565640701729755

Blumenfield, H.K., & Marian, V. (2007). Constraints on parallel activation in bilingual spoken language processing: examining proficiency and lexical status using eye-tracking. *Language and Cognitive Processes*, **22**, 633–660. doi:10.1080/01690960601000746

Bull, R., Espy, K.A., & Wiebe, S.A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: longitudinal predictors of mathmatical achievement at age 7 years. *Developmental Neuropsychology*, **33**, 205–228. doi:10.1080/87565640801982312

Calvo, A., & Bialystok, E. (2014). Independent effects of bilingualism and socioeconomic status on language ability and executive functioning. *Cognition*, **130**, 278–288.

Carlson, S.M., & Meltzoff, A.N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science*, **11**, 282–298. doi:10.1111/j.1467-7687.2008.00675.x

Crivello, C., Kuzyk, O., Rodrigues, M., Friend, M., Zesiger, P., et al. (2016). The effects of bilingual growth on toddlers' executive function. *Journal of Experimental Child Psychology*, **141**, 121–132. doi:10.1016/j.jecp.2015.08.004

Dunabeitia, J.A., Hernandez, J.A., Anton, E., Macizo, P., Estevez, A., et al. (2014). The inhibitory advantage in bilingual children revisited: myth or reality? *Experimental Psychology*, **61**, 234–251. doi:10.1027/1618-3169/a000243

Duncan, G.J., Ziol-Guest, K.M., & Kalil, A. (2010). Early childhood poverty and adult attainment, behavior, and health. *Child Development*, **81**, 306–325. doi:10.1111/j.1467-8624.2009.01396.x

Dunn, L.M., & Dunn, L.M. (1997). *Peabody Picture Vocabulary Test* (3rd edn.). Bloomington, MN: Pearson Assessments.

Elliott, R. (2003). Executive functions and their disorders. *British Medical Bulletin*, **65**, 49–59. doi:10.1093/bmb/ldg65.049

Engel de Abreu, P.M. (2011). Working memory in multilingual children: is there a bilingual effect? *Memory*, **19**, 529–537. doi:10.1080/09658211.2011.590504

Engle, R.W., Laughlin, J.E., Tuholski, S.W., & Conway, A.R. (1999). Working memory, short-term memory, and general fluid intellignece: a latent-variable approach. *Journal of Experimental Psychology: General*, **128**, 309–331.

Eriksen, B.A., & Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, **16**, 143–149.

Francis, W.S. (1999). Cognitive integration of language and memory in bilinguals: semantic representation. *Psychological Bulletin*, **125**, 193–222.

Gathercole, V.C., Thomas, E.M., Kennedy, I., Prys, C., Young, N., et al. (2014). Does language dominance affect cognitive performance in bilinguals? Lifespan evidence from preschoolers through older adults on card sorting, Simon, and metalinguistic tasks. *Frontiers in Psychology*, **5**, 11. doi:10.3389/fpsyg.2014.00011

Grainger, J. (1993). Visual word lexicon in bilinguals. In R. Schreuder & B. Weltens (Eds.), *The bilingual lexicon* (pp. 11–25). Amsterdam: John Benjamins.

Halperin, J.M., Trampush, J.W., Miller, C.J., Marks, D.J., & Newcorn, J.H. (2008). Neuropsychological outcome in adolescents/young adults with childhood ADHD: profiles of persisters, remitters and controls. *Journal of Child Psychology and Psychiatry*, **49**, 958–966. doi:10.1111/j.1469-7610.2008.01926.x

Hart, S.A., Petrill, S.A., Willcutt, E., Thompson, L.A., Schatschneider, C., et al. (2010). Exploring how symptoms of Attention-Deficit/Hyperactivity Disorder are related to reading and mathematics performance: general genes, general environments. *Psychological Science*, **21**, 1708–1715. doi:10.1177/0956797610386617

Kalashnikova, M., & Mattock, K. (2014). Maturation of executive functioning skills in early sequential bilingualism. *International Journal of Bilingual Education and Bilingualism*, **17**, 111–123. doi:10.1080/13670050.2012.746284

Kapa, L.L., & Colombo, J. (2013). Attentional control in early and later bilingual children. *Cognitive Development*, **28**, 233–246. doi:10.1016/j.cogdev.2013.01.011

Krizman, J., Skoe, E., & Kraus, N. (in press). Bilingual enhancements have no socioeconomic boundaries. *Developmental Science*. doi: 10.1111/desc.12347

Kroll, J.F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. *Journal of Cognitive Psychology*, **25**, 497–514. doi:10.1080/20445911.2013.799170

Kroll, J.F., Bobb, S.C., & Hoshino, N. (2014). Two languages in mind: bilingualism as a tool to investigate language, cognition, and the brain. *Current Directions in Psychological Science*, **23**, 159–163. doi:10.1177/0963721414528511

Kroll, J.F., & de Groot, A.M.B. (1997). Lexical and conceptual memory in the bilingual: mapping form to meaning in two languages. In A.M.B. de Groot & J.F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives* (pp. 169–199). Mahwah, NJ: Erlbaum.

Kroll, J.F., Dussias, P.E., Bogulski, C.A., & Valdes-Kroff, J. (2012). Juggling two languages in one mind: what bilinguals tell us about language processing and its consequences for cognition. In B. Ross (Ed.), *The psychology of learning and motivation*, Vol. **56** (pp. 229–262). San Diego, CA: Academic Press.

Lakes, K.D., Swanson, J.M., & Riggs, M. (2012). The reliability and validity of the English and Spanish Strengths and Weaknesses of ADHD and Normal behavior rating scales in a preschool sample: continuum measures of hyperactivity and inattention. *Journal of Attention Disorders*, **16**, 510–516. doi:10.1177/1087054711413550

Lambek, R., Tannock, R., Daslgaard, S., Trillingsgaard, A., Damm, D., et al. (2011). Executive dysfunction in school-age children with ADHD. *Journal of Attention Disorders*, **15**, 646–655. doi:10.1177/1087054710370935

Logan, G.D. (1994). On the ability to inhibit thought and action: a user's guide to the stop signal paradigm. In D. Dagenbach & T.H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189–239). San Diego, CA: Academic Press.

Logan, G.D., & Cowan, W.B. (1984). On the ability to inhibit thought and action: a theory of an act of control. *Psychological Review*, **91**, 295–327.

Logan, G.D., Schachar, R.J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science*, **8**, 60–64.

Lu, C.H., & Proctor, R.W. (1995). The influence of irrelevant location information on performance: a review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review*, **2**, 174–207. doi:10.3758/BF03210959

Lubke, G.H., Hudziak, J.J., Derks, E.M., Van Bijsterveldt, T.C., & Boomsma, D.I. (2009). Maternal ratings of attention problems in ADHD: evidence for the existence of a continuum. *Journal of the American Academy of Child and Adolescent Psychiatry*, **48**, 1085–1093. doi:10.1097/CHI.0b013e3181ba3dbb

Luk, G., & Bialystok, E. (2013). Bilingualism is not a categorical variable: interaction between language proficiency and usage. *Journal of Cognitive Psychology*, **25**, 605–621. doi:10.1080/20445911.2013.795574

Luk, G., de Sa, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control? *Bilingualism: Language and Cognition*, **14**, 588–595. doi: 10.1017/S1366728911000010

Luk, G., Green, D.W., Abutalebi, J., & Grady, C. (2012). Cognitive control for language switching in bilinguals: a quantitative meta-analysis of functional neuroimaging studies. *Language and Cognitive Processes*, **27**, 1479–1488. doi:10.1080/01690965.2011.613209

Luo, L., Craik, F.I.M., Moreno, S., & Bialystok, E. (2013). Bilingualism interacts with domain in a working memory task: evidence from aging. *Psychology and Aging*, **28**, 28–34. doi:10.1037/a0030875

Marian, V., & Spivey, M. (2003). Bilingual and monolingual processing of competing lexical items. *Applied Psycholinguistics*, **24**, 173–193. doi:10.1017/S0142716403000092

Martin-Rhee, M.M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, **11**, 81–93. doi: 10.1017/S1366728907003227

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with Attention-Deficit/Hyperactivity Disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, **44**, 377–384. doi:10.1097/01.chi.0000153228.72591.73

Miller, M., & Hinshaw, S.P. (2010). Does childhood executive function predict adolescent functional outcomes in girls with ADHD? *Journal of Abnormal Child Psychology*, **38**, 315–326. doi:10.1007/s10802-009-9369-2

Miller, M., Nevado-Montenegro, A., & Hinshaw, S.P. (2012). Childhood executive function continues to predict outcomes in young adult females with and without childhood diagnosed ADHD. *Journal of Abnormal Child Psychology*, **40**, 657–668. doi:10.1007/s10802-011-9599-y

Miyake, A., & Friedman, N.P. (2012). The nature and organization of individual differences in executive functions: four general conclusions. *Current Directions in Psychological Science*, **21** (1), 8–14. doi:10.1177/0963721411429458

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., et al. (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. doi:10.1006/cogp.1999.0734

Mor, B., Yitzhaki-Amsalem, S., & Prior, A. (2015). The joint effect of bilingualism and ADHD on executive functions. *Journal of Attention Disorders*, **19** (6), 527–541. doi:10.1177/1087054714527790

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology*, **114**, 187–202. doi:10.1016/j.jecp.2012.09.002

Mullane, J.C., Corkum, P.V., Klein, R.M., & McLaughlin, E. (2009). Interference control in children with and without ADHD: a systematic review of Flanker and Simon task performance. *Child Neuropsychology*, **15**, 321–342. doi:10.1080/09297040802348028

Petersen, S.E., & Posner, M.I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, **35**, 73–89. doi:10.1146/annurev-neuro-062111-150525

Poarch, G.J., & van Hell, J.G. (2012). Executive functions and inhibitory control in multilingual children: evidence from second-language learners, bilinguals, and trilinguals. *Journal of Experimental Child Psychology*, **113**, 535–551. doi:10.1016/j.jecp.2012.06.013

Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, **13**, 25–42. doi:10.1146/annurev.neuro.13.1.25

Rajendran, K., Rindskopf, D., O'Neill, S., Marks, D.J., Nomura, Y., et al. (2013). Neuropsychological functioning and severity of ADHD in early childhood: a four-year cross-lagged study. *Journal of Abnormal Psychology*, **122**, 1179–1188. doi:10.1037/a0034237

Raven, J.C. (2003). *Raven's Advanced Progressive Matrices*. San Antonio, TX: Pearson Assessment.

Rodriguez-Fornells, A., Rotte, M., Heinze, H.J., Nosselt, T., & Munte, T.F. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature*, **415**, 1026–1029. doi:10.1038/4151026a

Rousseeuw, P.J., & Croux, C. (1993). Alternatives to the median absolute deviation. *Journal of the American Statistical Association*, **88**, 1273–1283. doi:10.1080/01621459.1993.10476408

Senderecka, M., Grabowska, A., Szewczyk, J., Gerc, K., & Chmylak, R. (2012). Response inhibition of children with ADHD in the stop-signal task: an event-related potential study. *International Journal of Psychophysiology*, **85**, 93–105. doi:10.1016/j.ijpsycho.2011.05.007

Shallice, T., Burgess, P.W., & Robertson, I. (1996). The domain of supervisory processes and temporal organisation of behaviour. *Philosophical Transactions of the Royal Society B*, **351**, 1405–1412.

Shuster, J., & Toplak, M.E. (2009). Executive and motivational inhibition: associations with self-report measures related to inhibition. *Consciousness and Cognition*, **18**, 471–480. doi:10.1016/j.concog.2009.01.004

Sonuga-Barke, E.J.S. (2002). Psychological heterogeneity in AD/HD – a dual pathway model of behaviour and cognition. *Behavioral Brain Research*, **130**, 29–36. doi:10.1016/S0166-4328(01)00432-6

Sonuga-Barke, E.J.S. (2003). The dual pathway model of AD/HD: an elaboration of neurodevelopmental characteristics. *Neuroscience & Biobehavioral Reviews*, **27**, 593–604. doi:10.1016/j.neubiorev.2003.08.005

Sonuga-Barke, E.J.S. (2005). Causal models of Attention-Deficit/Hyperactivity Disorder: from common simple deficits to multiple developmental pathways. *Biological Psychiatry*, **57**, 1231–1238. doi: 10.1016/j.biopsych.2004.09.008

Sorper, D. (2011). *Interaction* (Version 1.6.2133).

Swanson, J., Schuck, S., Mann, M., Carlson, C., & Hartman, C. et al. (2001). Over-identification of extreme behavior in the evaluation and diagnosis of ADHD/HKD. From: http://www.adhd.net/SWAN_Paper.pdf.

Thierry, G., & Wu, Y.J. (2007). Brain potentials reveal unconscious translation during foreign-language comprehension. *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 12530–12535. doi:10.1073/pnas.0609927104

Thorell, L.B. (2007). Do delay aversion and executive function deficits make distinct contributions to the functional impact of ADHD symptoms? A study of early academic skill deficits. *Journal of Child Psychology and Psychiatry*, **48**, 1061–1070. doi:10.1111/j.1469-7610.2007.01777.x

Valicenti-McDermott, M., Tarshis, N., Schouls, M., Galdston, M., Hottinger, K., et al. (2013). Language differences between monolingual English and bilingual English-Spanish young children with autism spectrum disorders. *Journal of Child Neurology*, **28**, 945–948. doi:10.1177/0883073812453204

Willcutt, E.G. (2012). The prevalence of DSM-IV Attention-Deficit/Hyperactivity Disorder: a meta-analytic review. *Neurotherapeutics*, **9**, 490–499. doi:10.1007/s13311-012-0135-8

Willcutt, E.G., Doyle, A.E., Nigg, J.T., Faraone, S.V., & Pennington, B.F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biological Psychiatry*, **57**, 1336–1346. doi:10.1016/j.biopsych.2005.02.006

Williams, B.R., Ponessee, J.S., Schachar, R.J., Logan, G.D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology*, **35**, 205–213.

Yang, S., Yang, H., & Lust, B. (2011). Early childhood bilingualism leads to advances in executive attention: dissociating culture and language. *Bilingualism: Language and Cognition*, **14**, 412–422. doi: 10.1017/S1366728910000611

Young, D.J., Levy, F., Martin, N.C., & Hay, D.A. (2009). Attention deficit hyperactivity disorder: a Rasch analysis of

the SWAN rating scale. *Child Psychiatry and Human Development*, **40**, 543–559.
Zhou, B., & Krott, A. (in press). Data trimming procedure can eliminate bilingual cognitive advantage. *Psychonomic Bulletin & Review*. doi: 10.3758/s13423-015-0981-6

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