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The effects of bilingual growth on toddlers' executive function

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ABSTRACT

The mastery of two languages provides bilingual speakers with cognitive benefits over monolinguals, particularly on cognitive flexibility and selective attention. However, extant research is limited to comparisons between monolinguals and bilinguals at a single point in time. This study investigated whether growth in bilingual proficiency, as shown by an increased number of translation equivalents (TEs) over a 7-month period, improves executive function. We hypothesized that bilingual toddlers with a larger increase of TEs would have more practice in switching across lexical systems, boosting executive function abilities. Expressive vocabulary and TEs were assessed at 24 and 31 months of age. A battery of tasks, including conflict, delay, and working memory tasks, was administered at 31 months. As expected, we observed a task-specific advantage in inhibitory control in bilinguals. More important, within the bilingual group, larger increases in the number of TEs predicted better performance on conflict tasks but not on delay tasks. This unique longitudinal design confirms the relation between executive function and early bilingualism.

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Introduction

Bilingualism is a widespread phenomenon; it is estimated that half of the world's population speaks two or more languages (Grosjean, 2010). Due to this worldwide prevalence, the costs and benefits of bilingualism have increasingly become an important area of study in cognitive science. Researchers have demonstrated that there are cognitive advantages of bilingualism, particularly on tasks measuring cognitive flexibility and selective attention (Barac & Bialystok, 2012; Bialystok, 2001). These tasks require regulation of inhibitory mechanisms that allows one to focus attention on relevant information while suppressing attention toward misleading information (Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011). Such benefits are evident on tasks involving conflicting attentional demands (conflict tasks), but not on tasks measuring response suppression (delay tasks), as the benefits of executive function are conveyed through conflict inhibition (Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008; Poulin-Dubois et al., 2011). Conflict inhibition refers to the inhibition of attention to a mental representation, as opposed to response suppression, which refers to inhibition of a motor response (Carlson & Meltzoff, 2008; Poulin-Dubois et al., 2011). Despite the fact that many researchers have observed the cognitive benefits of bilingualism in adults (see review by Kroll & Bialystok, 2013) and children (see reviews by Adesope, Lavin, Thompson, & Ungerleider, 2010, and Bialystok, 2005), findings are inconsistent. To illustrate, recent studies comparing executive function abilities in monolingual and bilingual samples have found no such bilingual advantage (Antón et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2014; Paap & Greenberg, 2013). Finally, Hilchey and Klein (2011) found that cognitive advantages are robust in bilingual children; however, there is limited evidence regarding how early these advantages emerge (cf. Kovacs & Mehler, 2009). This is of particular relevance when we consider that many children acquire their languages simultaneously early in life.

The dominant explanation for bilinguals' enhanced executive control is that both languages are simultaneously activated in the bilingual brain and, thus, these executive functions are continuously used to focus on the target language and disregard the non-target language (Colomé, 2001; Green, 1998; Kroll, Dussias, Bogulski, & Kroff, 2012; Rodriguez-Fornells et al., 2005). Moreover, bilinguals need to repeatedly direct their attention between language systems as a function of the linguistic context (Bialystok, 2008). The ongoing coordination of competing lexical systems prevents disruptions in speech and maintains fluency in either language and, in turn, strengthens executive function abilities (Bialystok, 2001).

There is evidence of enhanced selective attention and cognitive flexibility as a function of repeated practice. Bilinguals who began using both languages later in life show greater interference on a conflict task than bilinguals who began using both languages early in life (Luk, De Sa, & Bialystok, 2011; Poarch & van Hell, 2012). In addition, studies examining this effect during childhood have revealed that the bilingual advantage becomes more apparent as children grow older and obtain more practice in language control. To illustrate, Poulin-Dubois and colleagues (2011) found a bilingual advantage on one of three conflict tasks in 2-year-olds, whereas Bialystok, Barac, Blaye, and Poulin-Dubois (2010) found an effect on three of four tasks measuring executive control in 3- and 4-year-olds. Thus, the effect of bilingualism on executive function is stronger and apparent on more tasks as children gain practice in managing both languages.

As bilinguals actively use both languages, they create two lexical representations for one concept in either language, also referred to as translation equivalents (TEs; e.g., *dog* and *chien*). Children acquire TEs early on in language development, and the proportion of TEs is directly related to the amount of second language exposure (Genesee & Nicoladis, 2007; Pearson, Fernandez, Lewedeg, & Oller, 1997). The acquisition of TEs allows the bilingual child to acquire more experience in inhibiting one language while using the other. In accordance with the acquisition of TEs, research using semantic priming to examine language switching in young bilinguals has shown that bilingual toddlers are able to retrieve words in their second language once primed by a related word in their first language. Singh (2014) speculated that words are accessed and processed from independent language systems. This requires bilinguals to switch across language systems, thereby strengthening their selective attention and inhibition abilities (Patterson & Pearson, 2004). It is hypothesized that these abilities would be enhanced as a function of TE acquisition.

Across numerous studies examining executive function abilities, researchers have indicated that bilingual experience has a substantial effect on children's cognitive performance. To illustrate, executive function benefits of bilingualism have been reported by Carlson and Meltzoff (2008), whereby 6-year-old bilinguals outperformed their monolingual counterparts on conflict tasks but not on delay tasks. Poulin-Dubois and colleagues (2011) reported similar findings with 24-month-old bilinguals and monolinguals. The bilinguals outperformed the monolinguals on the Shape Stroop task, a conflict task in which children need to selectively attend to a target stimulus while ignoring a non-target stimulus, but comparable between-group performance was observed on the delay tasks. There is even some evidence of executive function benefits during infancy on tasks measuring inhibitory control (Kovacs & Mehler, 2009) and memory generalization (Brito & Barr, 2012, 2014; Brito, Grenell, & Barr, 2014).

Although the link between executive function and bilingualism is a hot topic in the literature, studies examining such bilingual advantage early on in development are limited and most of the evidence of bilingual cognitive benefits comes from research on older children and adults. Furthermore, the majority of research in this field involves comparisons between monolinguals and bilinguals and studies examining within-bilingual comparisons are scarce (but see Wu & Thierry, 2013). As such, some researchers remain critical of these group comparisons given that extraneous variables may have confounded results (e.g., socioeconomic status, culture) (Morton & Harper, 2007). In addition to examining differences in executive function performance across monolingual and bilingual toddlers, the current study is the first to investigate the effects of vocabulary growth (particularly with regard to TEs) in bilingualism. Blom, Küntay, Messer, Verhagen, and Leseman (2014) studied the relation between executive function and bilingualism using a longitudinal design by comparing monolinguals and bilinguals at two time points concurrently. However, the current study is the first to measure bilingual acquisition longitudinally while examining its influence on executive function mechanisms. Such design offers a unique opportunity to assess the cognitive underpinnings of a putative bilingual advantage early in development while controlling for group inequalities.

The goal of the current study was to replicate previous studies demonstrating a bilingual advantage when comparing monolingual and bilingual young children on conflict tasks. More important, the main goal was to examine mechanisms that may underlie the cognitive advantages in bilinguals. Thus, we investigated whether an increased number of TEs during the second and third years of life predicts performance on executive function tasks. We reasoned that such an increase provides additional opportunity for practicing switching between languages, thereby boosting the cognitive processes that are assumed to benefit from bilingualism. Executive function consists of separable components that are related, specifically updating, switching, and inhibiting (Miyake et al., 2000); therefore, executive function tasks measuring different mechanisms were included in the current study. In particular, children's ability to respond to conflicting attentional demands and their working memory and response suppression abilities were assessed through these tasks. With regard to conflict tasks, we adopted Bunge, Dudukovic, Thomason, Vaidya, and Gabrieli's (2002) model of inhibition in which there is a distinction in inhibitory control between interference suppression and response inhibition. Interference suppression occurs when there are bivalent displays that have two conflicting responses. Contrarily, response inhibition consists of univalent displays in which there is only one feature present. We can think of bilinguals' two lexical systems acting as bivalent displays, such that bilinguals need to focus on the target language and ignore the non-target language to resolve conflict between their two languages, which parallels interference suppression (Martin-Rhee & Bialystok, 2008). Similarly, Bialystok and Martin (2004) differentiated between two types of inhibition mechanisms: response inhibition (e.g., avoid carrying out a familiar motor response) and conceptual inhibition (e.g., disregard a feature that was previously relevant and focus on a feature that is currently relevant). This led us to hypothesize that toddlers who show a greater increase in the number of TEs during the toddler period will show superior performance on executive function conflict tasks but not on delay or working memory tasks. It is important to note that executive function was assessed at only one time point, but the index of bilingualism (i.e., number of TEs) was assessed longitudinally. Examining growth in the number of TEs during this critical period of language development provides us with the opportunity to directly measure how increased cross-language switching influences executive function abilities.

Method

Participants

A total of 92 participants—49 bilinguals and 43 monolinguals—were tested. Bilingual participants were tested in Montréal, Québec (Canada), and were recruited from birth lists provided by a governmental health agency, whereas monolingual participants were tested in San Diego, California (United States), and were recruited through birth records and flyers. Of these 49 bilingual participants, 10 were excluded due to missing the second wave of data collection ($n = 4$) and missing a vocabulary measure ($n = 6$). After these exclusions, 39 bilingual participants remained. For bilinguals, language requirements consisted of being exposed to English and French from birth and having at least 20% exposure to their second language (L2). If the child was exposed to a third language, it was at or below 10%. For monolinguals, language requirements consisted of having at least 90% exposure to English. At Wave 1, bilingual participants had an L2 exposure between 21% and 50% ($M = 35.54\%$, $SD = 9.60$) and were between 22.10 and 25.40 months of age ($M = 24.00$ months, $SD = 0.88$). At Wave 2, bilingual participants had an L2 exposure between 22% and 50% ($M = 36.15\%$, $SD = 8.47$) and were between 28.80 and 33.50 months of age ($M = 30.91$ months, $SD = 1.02$). To provide further information on the composition of the bilingual group, balance in exposure was calculated by dividing participants' first language (L1) exposure by their L2 exposure (with a balance score of 1 being the most balance). At Wave 1 the mean balance score in exposure was 2.04 ($SD = 0.88$, range = 1.00–3.76), and at Wave 2 it was 1.94 ($SD = 0.73$, range = 1.00–3.55). In terms of the monolingual sample, at Wave 1 monolingual participants had an L1 exposure between 91.60% and 100% ($M = 98.83\%$, $SD = 2.36$) and were between 22.00 and 22.50 months of age ($M = 23.18$ months, $SD = 0.69$), and at Wave 2 monolingual participants had an L1 exposure between 91% and 100% ($M = 98.86\%$, $SD = 2.26$) and were between 29.80 and 32.90 months of age ($M = 30.95$ months, $SD = 0.78$).

Measures

Language Exposure Questionnaire

The Language Exposure Questionnaire (LEQ) has been used in previous studies to differentiate bilinguals from monolinguals (Bosch & Sebastián-Gallés, 1997; Fennell, Byers-Heinlein, & Werker, 2007). The experimenter administered an electronic adaptation of the LEQ (DeAnda, Arias-Triejo, Poulin-Dubois, Zesiger, & Friend, in press) through a semi-structured interview with the child's parents in which they were asked about who converses with their child on a weekly basis (e.g., parents, grandparents, educators) and what language they speak to their child and for how many hours. A global estimate of the proportion of time the child is exposed to each language was calculated.

MacArthur–Bates Communicative Development Inventory

The MacArthur–Bates Communicative Development Inventory: Words and Sentences (MCDI: WS) is a parent report vocabulary checklist that measures toddlers' expressive vocabulary and translation equivalents. The English version (Fenson et al., 1993) and the French Canadian version (Trudeau, Frank, & Poulin-Dubois, 1999) contain 680 and 624 words, respectively, and include nouns, verbs, and adjectives that are appropriate for toddlers 16 to 30 months of age.

Executive function tasks

Four executive function tasks were administered and consisted of two conflict tasks, a delay task, and a working memory/response control task. These tasks were chosen based on a battery of tasks from Carlson (2005) that have been used to measure executive function in toddlers.

Conflict tasks. Reverse Categorization task. The Reverse Categorization task (adapted from Carlson, Mandell, & Williams, 2004) is a measure of cognitive flexibility that consists of a pre-switch phase and a post-switch phase. The experimenter presented the child with a big bucket and a little bucket and then set them aside. Six big blocks and six little blocks were then presented to the child, and the child was given 20 s to play with them. In the pre-switch phase, the experimenter placed the buckets back on the table, and demonstrated that the little blocks go in the little bucket and the big blocks go in the big bucket. The child was asked to help for 6 trials. The experimenter verbally repeated the rule, gave the child the block, and placed the two buckets in front of him or her for each trial. In the post-switch phase, the experimenter said that they were going to play a silly game where they would put the little blocks in the big bucket and put the big blocks in the little bucket. The same procedure was followed for a total of 12 trials. The number of correct trials from the post-switch phase was recorded. This is considered a conflict task because the child needs to inhibit the previously learned rule and focus on the relevant rule to engage in the task correctly.

Shape Stroop task. The Shape Stroop task (adapted from Kochanska, Murray, & Harlan, 2000) is a measure of inhibitory control that consists of an identification phase and a Stroop phase. In the identification phase, the experimenter presented the child with three colored images of fruits (apple, banana, and orange) and then presented the child with the same fruits but smaller in size aligned below the larger fruit. The experimenter then labeled each of the six fruits by name and size. Following this, the images of the smaller fruits were removed and the experimenter asked the child to point to each fruit. Verbal reinforcement was given as well as the correct answer if necessary. In the Stroop phase, the experimenter presented the child with three colored images of small fruits embedded in different larger fruits (e.g., a small apple in a big banana). The experimenter then asked the child to point to each little fruit (e.g., "Show me the little apple"), and no feedback was provided. The number of trials from the Stroop phase where the child correctly identified the little fruits was recorded. This is considered a conflict task because the child needs to inhibit the distracting larger fruit and focus on the relevant small fruit to engage in the task correctly.

Delay task. Gift Delay task. The Gift Delay task (adapted from Kochanska et al., 2000) is a measure of response suppression. First, the experimenter placed a gold gift bag on the table and told the child that he or she was getting a gift for doing such a great job. Following this, the experimenter looked at the gift bag and told the child, "Uh oh! I forgot the bow! Let me go get it. But let's play another game. Sit here and don't open the present until I come back with the bow. Don't touch the gift until I come back with the bow, okay?" The experimenter then left the room for 3 min or until the child opened the gift. The child was given a score from 1 to 5 (1 = *pulls gift from bag,* 2 = *searches bag,* 3 = *touches bag many times,* 4 = *touches bag once,* 5 = *does not touch bag*).

Response control and working memory task. Multilocation task. The Multilocation task (adapted from Zelazo, Reznick, & Spinazzola, 1998) is a measure of working memory and response control that consists of a pre-switch phase and post-switch phase. A wooden box with five drawers was placed in front of the child, with the center drawer having a knob with an animal on it. The two drawers adjacent to the center drawer had no knobs and were glued shut, whereas the farthest right and farthest left drawers were bare but not glued shut. During the warm-up trial, the experimenter put a treat in the center drawer and showed the child how to retrieve the treat. The pre-switch phase followed the warm-up trial, whereby the experimenter switched the farthest right and farthest left drawers to new drawers with knobs of two different animals. The experimenter hid a treat in the center drawer and said, "Here is the treat," and pointed to the correct location. The experimenter then pointed to the farthest right and farthest left drawers and said, "There is no treat here". A towel was then placed on the wooden box, and the child was asked to find the treat. The pre-switch phase ended once the child retrieved the treat from the center drawer three times in a row. Following this, the post-switch phase was administered, whereby the experimenter hid the treat in either the farthest right or farthest left drawer through counterbalancing and followed the same script showing the child where the treat was located. However, a 10 s delay was imposed before asking the child to find the treat. The number of trials (maximum of 6) required to find the treat in the new location was recorded.

Procedure

Monolingual and bilingual participants visited the laboratory at Wave 1 when they were 24 months of age. The LEQ was administered to the parents to ensure that participants met the criteria for bilingualism. Following this, parents were instructed on how to fill out the MCDI: WS. For the bilinguals, if the parents were experts in English and/or French, they were asked to complete the vocabulary checklist. If not, then someone who communicates with the child in that language and who has a good knowledge of the child's vocabulary completed the questionnaire (e.g., educator, grandparents). Parents of monolingual participants were also asked to complete the MCDI: WS. The number of TEs was calculated using the MCDI: WS by subtracting the number of cognate pairs (e.g., *block* and *bloc*) and semi-cognate pairs (e.g., *mittens* and *mitaines*) from the TE pairs. Cognates and semi-cognates were subtracted from the TE pairs because they can inflate TEs due to their similar phonology (Bosch & Ramon-Casas, 2014). Non-equivalents are words that do not have a translation on the MCDI: WS. Conceptual vocabulary was also assessed through the MCDI: WS by subtracting the TEs from the total number of words produced.

Monolingual and bilingual participants returned to the laboratory 7 months later (M = 6.90 months, SD = 0.55) when they were 31 months old, and the same procedure was administered. However, at this wave, executive function tasks were added to the procedure and were administered in the child's dominant language in a fixed order (Multilocation task, Reverse Categorization task, Shape Stroop task, Gift Delay task). All of these tasks at Wave 2 were administered on a table where the child sat across from the experimenter in a high chair, with the caregiver(s) sitting behind the child. At both waves, parents received $25 financial compensation, and the child received a gift and a certificate of merit.

Results

Between-group comparisons

The vocabulary of the two groups was first analyzed to compare participants' language abilities. In line with previous research, a significant difference was found between monolinguals and bilinguals in their L1 on the MCDI, $t(80) = 3.06$, $p = .003$, $d = 0.68$. Monolinguals produced an average of 523.07 words (SD = 163.10), whereas bilinguals produced an average of 419.13 words (SD = 141.93) in their L1. Similarly, monolinguals' vocabulary (M = 523.07, SD = 163.10) was slightly higher than bilinguals' conceptual vocabulary (total vocabulary minus translation equivalents) (M = 457.92, SD = 142.62), $t(80) = 1.92$, $p = .06$, $d = 0.43$. Furthermore, there were no significant differences in age, $t(80) = 1.90$, $p = .85$, gender, $\chi^2 = 1.79$, $p = .18$, or maternal education, $t(80) = -1.37$, $p = .18$. A series of independent t-tests were computed to compare bilinguals and monolinguals on the conflict tasks, Gift Delay task, and Multilocation task. Despite differences in sample size, the groups had roughly equal variances and similar minimum and maximum values across tasks (Baguley, 2012).

Conflict tasks

To obtain a composite estimate of set-shifting, we combined the scores on the Shape Stroop and Reverse Categorization tasks by calculating the total score. These two tasks were combined because they were highly correlated, $r(70) = .34$, $p = .003$, and measure the same construct. A total of 29 bilingual participants were included in the conflict tasks because an additional 10 bilinguals were excluded due to fussiness (n = 6) or failure to pass the training trials (n = 4). The Reverse Categorization task had the largest number of exclusions. According to Carlson (2005), this is the most difficult task from the battery of executive function tasks for toddlers. It also involves a lot of verbal instructions by the experimenter compared with other tasks. Although we presented the task in bilinguals' L1, their L1 expressive vocabulary was smaller than that of monolinguals, and this may have made the Reverse Categorization task particularly challenging for some bilinguals. To test this idea, we calculated mean L1 vocabulary for our exclusions (M = 328.60, SD = 170.04) relative to the children who completed the task (M = 450.34, SD = 118.79). Children who completed the task had higher expressive vocabularies in

Table 1
Mean scores on the executive function tasks for each group.

	Monolinguals			Bilinguals		
	M	*SD*	Range	*M*	*SD*	Range
Composite conflict tasks						
Proportion of correct pre-switch trials	.92	.15	.44–1.00	.94	.13	.33–1.00
Proportion of correct post-switch trials	.54	.32	0–1.00	.69	.31	0–1.00
Gift Delay task						
Scale score	3.79	1.26	1–5	3.23	1.40	1–5
Multilocation task						
Number of correct trials	1.15	0.48	1–3	1.37	0.67	1–3

L1, $t(37) = -2.495$, $p = .017$. All 43 monolingual participants were included in the conflict tasks. The mean proportion of correct responses in the pre-switch trials was .94 ($SD = .13$) for bilingual participants and .92 ($SD = .15$) for monolingual participants. No significant difference was found between the groups on the pre-switch trials, $t(70) = -0.66$, $p = .51$, $d = -0.17$. In terms of post-switch trials, the mean proportion of correct responses was .69 ($SD = .31$) for bilingual participants and .54 ($SD = .32$) for monolingual participants. As expected, bilinguals had superior performance to monolinguals on the post-switch trials of the conflict tasks, although this effect was marginally significant, $t(70) = -1.99$, $p = .05$, $d = -0.48$ (see Table 1).

Gift Delay task

A total of 35 bilingual participants were included in the Gift Delay task because an additional 4 bilinguals were excluded due to fussiness ($n = 1$) or parental interference ($n = 3$). All 43 monolingual participants were included in this task. Bilingual participants obtained a mean score of 3.23 ($SD = 1.40$) and monolinguals participants obtained a mean score of 3.79 ($SD = 1.26$), indicating that on average participants in both groups touched the gift bag many times when the experimenter was not present in the room. As expected, the bilinguals did not have a superior performance on the Gift Delay task. In fact, the monolinguals performed better than the bilinguals at the trend level, $t(76) = 1.85$, $p = .07$, $d = 0.42$ (see Table 1). This highlights the distinction between response inhibition (e.g., gift delay) and conceptual inhibition (e.g., conflict) that drives our hypotheses. We expected bilingual children to be better at conceptual inhibition but were agnostic with regard to response inhibition.

Multilocation task

A total of 38 bilingual participants and 40 monolingual participants were included in the Multilocation task because an additional 4 participants (1 bilingual and 3 monolinguals) were excluded due to parental interference ($n = 1$), fussiness ($n = 1$), or not completing the pre-switch trials ($n = 2$). In addition, 2 outliers in the bilingual group and 1 outlier in the monolingual group were found and were transformed to the next most extreme score within 3 standard deviations from the mean. The mean number of trials it took to retrieve the treat three times in a row in the pre-switch phase was 3.34 ($SD = 1.19$) for bilingual participants and 2.90 ($SD = 0.44$) for monolingual participants. The mean number of trials it took to retrieve the treat in the new location in the post-switch trials was 1.37 ($SD = 0.67$) for bilingual participants and 1.15 ($SD = 0.48$) for monolingual participants. As expected, no significant difference was found between the bilinguals and monolinguals on the post-switch trials of the Multilocation task, $t(76) = -1.65$, $p = .10$, $d = -0.38$ (see Table 1).

Bilingual within-sample comparisons

We first examined bilinguals' conceptual vocabulary and number of TEs at both waves. Participants had a mean conceptual vocabulary of 262.87 words ($SD = 162.22$) at Wave 1 and 457.92 words

(SD = 142.62) at Wave 2, confirming an increase in conceptual vocabulary (SD = 99.93), $t(38) = 12.19$, $p < .001$, $d = 1.28$. A positive correlation between conceptual vocabulary at Wave 1 and Wave 2 was found, $r(37) = .79$, $p < .001$. In addition, participants' mean number of TEs was 92.79 (SD = 100.19) (proportion of TEs: M = 46.89%, SD = 19.00) at Wave 1 and 182.95 (SD = 134.77) (proportion of TEs: M = 57.75%, SD = 25.05) at Wave 2, $t(38) = 4.64$, $p < .001$, $d = 0.76$. A positive correlation between the number of TEs at Wave 1 and Wave 2 was also observed, $r(37) = .50$, $p = .001$.

Zero-order correlations were first computed between the difference in the number of TEs across waves and executive function scores. The change in the number of TEs from Wave 1 to Wave 2 was significantly correlated with performance on the conflict tasks, $r(27) = .558$, $p = .002$. There was also a significant positive correlation between the number of TEs at Wave 2 and performance on the conflict tasks, $r(27) = .416$, $p = .025$. No such effect was found between the change in the number of TEs and performance on the Gift Delay task, $r(33) = -.186$, $p = .285$. A positive correlation was also found between the change in the number of TEs and performance on the Multilocation task at the trend level, $r(36) = .302$, $p = .065$. Furthermore, no significant link was found in the change in vocabulary scores from Wave 1 to Wave 2 and performance on the conflict tasks for the monolinguals, $r(72) = .05$, $p = .679$.

A series of three hierarchical multiple regression analyses were conducted to evaluate how well an increase in the number of TEs during the second and third years of life predict performance on executive function tasks. However, to ensure that the relation between these conflict executive function tasks and an increase in the number of TEs was not due solely to a larger increase in vocabulary size, the difference score in conceptual vocabulary was included as a predictor. For each regression, a difference score representing the change in children's conceptual vocabulary from Wave 1 to Wave 2 was entered in Step 1, and the change in the number of TEs from Wave 1 to Wave 2 was entered in Step 2. The criterion variable was performance on the conflict tasks, Gift Delay task, and Multilocation task at Wave 2.

Conflict tasks

In Step 1 of the regression model, the difference score of conceptual vocabulary explained only 2.3% of the variance in performance on the conflict tasks. When the difference score of the number of TEs was added to the model in Step 2, the predictor explained an additional 29.00% of the variance in performance on the conflict tasks above and beyond the variance explained by the difference score of conceptual vocabulary, $\Delta R^2 = .29$, $\Delta F(1, 26) = 11.00$, $p = .003$ (see Table 2). Thus, the difference score of the number of TEs significantly predicted performance on the conflict tasks, $\beta = .58$, $t(28) = 3.32$, $p = .003$. In other words, a larger increase in the number of TEs from Wave 1 to Wave 2 is associated with a higher number of correct post-trials on the conflict tasks. These results indicate that the predictive power of the difference score of the number of TEs is approximately 12 times greater than that of the difference score of conceptual vocabulary. Importantly, there was no significant relation between change in the number of TEs and performance on the pre-trials in the conflict tasks, $\beta = .06$, $t(28) = 0.31$, $p = .76$, indicating that the trend can be attributed exclusively to those trials that required a shift in set.

Table 2
Conflict task scores regressed on growth of the number of TEs, controlling for growth of conceptual vocabulary.

Predictor	B	SE	β	t	p	ΔR^2
Step 1						.023
Difference score in conceptual vocabulary	.000	.001	.152	0.797	.432	
Step 2						.290
Difference score in conceptual vocabulary	.000	.001	−.053	−0.306	.762	
Difference score in the number of TEs	.001	.000	.577	3.316	.003	

Table 3
Gift Delay task scores regressed on growth of the number of TEs, controlling for growth of conceptual vocabulary.

Predictor	*B*	*SE*	*β*	*t*	*p*	ΔR^2
Step 1						.032
Difference score in conceptual vocabulary	.002	.002	.180	1.051	.301	
Step 2						.078
Difference score in conceptual vocabulary	.004	.002	.300	1.653	.108	
Difference score in the number of TEs	−.004	.002	−.304	−1.677	.103	

Gift Delay task

In Step 1 of the regression model, the difference score of conceptual vocabulary explained 3.2% of the variance in performance on the Gift Delay task. When the difference score of the number of TEs was added to the model in Step 2, the predictor explained only an additional 7.8% of the variance in performance on the Gift Delay task above and beyond the variance explained by the difference score of conceptual vocabulary, $\Delta R^2 = .078$, $\Delta F(1, 34) = 2.81$, $p = .103$ (see Table 3). As expected, change in the number of TEs did not significantly predict performance on the delay task, $\beta = -.30$, $t(34) = -1.68$, $p = .10$.

Multilocation task

In Step 1 of the regression model, the difference score of conceptual vocabulary explained only 1% of the variance in performance on the Multilocation task. When the difference score of the number of TEs was added to the model in Step 2, the predictor explained only an additional 9.7% of the variance in performance on this task above and beyond the variance explained by the difference score of conceptual vocabulary, $\Delta R^2 = .10$, $\Delta F(1, 35) = 3.77$, $p = .06$. The change in the number of TEs predicted performance on the Multilocation task at the trend level, $\beta = .335$, $t(37) = 1.94$, $p = .06$.

Discussion

The current research provides a unique contribution to the literature on the cognitive benefits of bilingualism in that this is the first study to assess the cognitive advantages of becoming more bilingual. In addition to examining differences in executive function abilities between monolingual and bilingual toddlers, the design of the current study allowed for within-group comparison in order to investigate mechanisms to explain the superior performance of the bilingual group. Consequently, we were able to assess whether becoming more fluent in two languages, as shown by increases in the number of TEs over 7 months, predicts later executive function abilities. We replicated previous research showing a bilingual advantage exclusively on the executive function conflict tasks, such that bilinguals marginally outperformed their monolingual counterparts. Moreover, as anticipated, a larger increase in toddlers' number of TEs predicted stronger executive function mechanisms. What is noteworthy is that the observed effect was specific to those executive function abilities on which bilingual individuals typically show an advantage (e.g., inhibition of attention to conflicting responses) but not to others (e.g., response suppression). Moreover, only the measure of increase in bilingualism (translation equivalents), and not vocabulary growth per se, predicted the cognitive benefits. In addition, there was no relation between the growth in vocabulary and performance on conflict tasks for the monolinguals, which provides further evidence that the use of both languages is required to produce this cognitive advantage. This supports the notion that language switching underlies the bilingual advantage on conflict tasks. The current study is the first to look at variability in fluency among young bilinguals and executive function using a longitudinal design and offers a new way in which to examine this relation. Furthermore, our within-sample design addresses some of the concerns raised about the numerous studies based on between-group comparisons (monolinguals vs. bilinguals) because these results have been challenged due to potential confounding variables such as socioeconomic status (SES; Morton & Harper, 2007). However, a bilingual advantage has also been reported independently of extraneous variables such as SES (Calvo & Bialystok, 2014).

As in a previous study comparing executive function in monolingual and bilingual toddlers (Poulin-Dubois et al., 2011), a battery of tasks was administered to evaluate different aspects of executive function, including selective attention, cognitive flexibility, and response inhibition. It is important to assess both conflict inhibition and response suppression because prior studies have shown that bilinguals do not outperform monolinguals on all measures of inhibition (Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008; Poulin-Dubois et al., 2011). Bilingual children typically show superior performance on conflict tasks in which they are required to inhibit their attention to a non-target stimulus and focus on the relevant one, but this group difference is not found on delay tasks in which they are required to suppress a desired action (Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008; Poulin-Dubois et al., 2011). Furthermore, many studies have found no bilingual advantage on tasks assessing working memory (e.g., Bialystok, Craik, & Luk, 2008; Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012), with bilingual advantages appearing only from working memory tasks that impose subsequent cognitive demands (Morales, Calvo, & Bialystok, 2013). An increase in the number of TEs from Wave 1 to Wave 2 marginally predicted performance on the Multilocation task. This task has perhaps more cognitive demands than initially expected because there is also a conflict between two responses (pre- vs. post-switch). Overall, our results are consistent with previous research in two ways: Bilingual toddlers outperformed monolinguals only on conflict tasks, and change in the number of TEs from Wave 1 to Wave 2 predicted performance on the executive function conflict tasks. In support of our hypothesis, it appears that as bilingual toddlers progress through lexical development and acquire more TEs in their expressive vocabularies, their cognitive flexibility and selective attention is enhanced. Therefore, we would expect this effect to be more robust later in childhood as children become more proficient in both languages.

The current findings are consistent with recent cross-sectional studies showing a gradient in the cognitive advantages of bilingualism as a function of practice. Studies have shown that individuals who learn a second language earlier in life and actively use both languages more frequently have a superior performance on conflict tasks than individuals who learn a second language later on and do not use both languages as frequently (Luk et al., 2011; Poarch & van Hell, 2012). Furthermore, studies have demonstrated that the differences in executive function abilities between monolinguals and bilinguals become larger as children grow older (Bialystok et al., 2010; Poulin-Dubois et al., 2011). Based on this previous research, we used a direct measure of practice by examining increases in the number of TEs in expressive vocabulary from 24 to 31 months of age. It was theorized that toddlers would acquire more practice in control over which language to choose given the speaking context while avoiding interference from the language not in use. Given that increases in conceptual vocabulary score had a weaker association with performance on conflict tasks compared with increases in the number of TEs, it appears that the ability to produce words in two languages is central to strengthening executive function in bilingual children.

It is worth noting that approximately 46% of children's expressive vocabulary was made up of TEs at Wave 1 and approximately 57% at Wave 2, with considerable variability across children. This finding provides evidence that by the end of the third year of life, the average bilingual child uses two words for most concepts in his or her vocabulary. Thus, young bilingual children develop experience in switching across lexical systems, and this switching becomes more frequent as children grow older and as their vocabulary size increases. Therefore, the superior performance on these conflict tasks appears to be due to bilinguals' strengthened cognitive flexibility and selective attention abilities as they have increased experience in switching across languages in expressive vocabulary.

It is important to note that the change in the number of TEs does not account for the majority of variance in performance on executive function conflict tasks. One explanation is that the number of TEs is only a proxy of language switching in that it is not directly measuring how frequently a bilingual child switches across language systems. For example, two children might have the same number of TEs in their vocabulary but may have different opportunities to switch across languages. Future research should examine whether increased use of TEs represents a stronger predictor of performance on conflict tasks.

In sum, the current study offers a unique insight into the cognitive benefits of bilingualism. Our results demonstrate that learning translation equivalents positively affects executive function early in development ostensibly through children's increased opportunities for switching across lexical systems. Furthermore, the current findings support the prevailing hypothesis in the literature that, relative to monolinguals, bilinguals have superior selective attention and inhibitory control through focusing their attention to the target language and ignoring the non-target language. The current study provides evidence in a unique way that the bilingual advantage stems from extensive practice of these executive function abilities early in development.

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