The Effects of Bilingualism and Vocabulary Size on Infants' Cognitive Control

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ABSTRACT

The Effects of Bilingualism and Vocabulary Size on Infants' Cognitive Control

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There is increasing evidence that bilingualism may lead to cognitive advantages, and some evidence suggests that these may emerge as early as infancy. The present study examined if such advantages could be found in preverbal bilingual infants (7-month-olds), and older bilingual infants who have an emerging vocabulary (20-month-olds). We compared monolinguals and bilinguals in an anticipatory eye movement paradigm. During the training phase, infants learned to use a visual and auditory cue to anticipate a visual reward on one side of a screen. During the test phase, the reward would appear on the opposite side of the screen, necessitating infants to inhibit the previously-learned rule. Results suggest that both 7-month-old and 20-month-old bilingual infants were better able to inhibit their previously learned response than monolinguals. This effect was most apparent in the middle block of test trials. At 20 months, infants with lower vocabulary size were more engaged in the task, showing more total anticipations (both correct and incorrect) than those with higher vocabulary size. Overall, this research provides some evidence that bilingualism may lead to improvements in cognitive control for preverbal and older infants.

Keywords: infancy, bilingualism, cognitive control, inhibitory control, eye-tracking

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Contribution of Authors

The project was designed by Sadaf Pour Iliaei and Dr. Krista Byers-Heinlein. Sadaf Pour Iliaei created the stimuli, coordinated data collection, analyzed the data, and wrote the manuscript. Dr. Krista Byers-Heinlein provided critical feedback for all the steps mentioned above.

Table of Contents

List of Tables

List of Figures

The Effects of Bilingualism and Vocabulary Size on Infants' Cognitive Control

Bilingual infants are unique because they must acquire two languages simultaneously. Contrary to early warnings about potential disadvantages of growing up bilingual (Epstein, 1905, Yoshioka, 1929, Macnamara, 1966), there is increasing evidence that bilingualism leads to metalinguistic awareness (Edwards & Christophersen, 1988; Yelland, Pollard, & Mercuri, 1993) as well as cognitive advantages (Bialystok, 2007; Bialystok & Viswanathan, 2009). The positive impact of bilingualism on cognitive functions has been reported many times in studies with children (Barac & Bialystok, 2011; Bialystok, 2010; see reviews by Adesope, Lavin, Thompson, & Ungerleider, 2010; Barac et al., 2014), young and middle-aged adults (Costa, Hernandez, & Sebastián-Gallés, 2008) and older adults, (Bialystok, Craik, & Freedman, 2007; Kave´, Eyal, Shorek, & Cohen-Mansfield, 2008). While bilingual benefits have been observed across the lifespan, the age at which the two languages are acquired appears to modulate this effect. Bilingual adults who learned two languages in infancy show enhancements in cognitive control and brain connectivity relative to adults who learned their second language later in life (Kousaie, Chai, Sander, & Klein, 2017). One potential explanation of these results is that bilingual experience in infancy has special effects on cognition. However, very few studies have directly investigated the cognitive effects of bilingualism in bilingual infants. The current research aims to better understand the effect of bilingualism on infant's early cognitive control by addressing the question of how and when such effect arises, and how its trajectory is influenced by speech development.

Enhanced cognitive performance in bilinguals

A large body of empirical research on cognitive gains of bilinguals is based on studies comparing monolinguals and bilinguals on a variety of cognitive tasks. These tasks usually measure one aspect of cognitive functions known as executive functions (see Barac & Bialystok, 2011; Hilchey & Klein, 2011, for reviews). Executive functions refer to mental processes which help us to concentrate and pay attention, flexibly ignore unnecessary information and quickly adapt to changed circumstances (Diamond, 2013). Executive functions have core components such as switching flexibly between mental tasks, updating working memory contents, and inhibitory control (Miyake et al., 2000), which is defined as the ability to suppress a prepotent response (Barkley, 1997). Many theorists argue that better inhibitory control in bilinguals arises because they must constantly inhibit one language over the other (Green, 1998; Meuter & Allport, 1999). One proposal by Green (1998) proposes that during speech production, bilinguals employ a mental control over their two language systems. Since only one language should be spoken at a time, bilinguals need to select representations from their target language while constantly inhibiting the other language. Therefore, both languages are jointly activated (Kroll & de Groot, 1997; van Heuven et al., 2008), but each at a different level. It has been suggested that continuous practice of monitoring and selecting languages by bilinguals may improve a general control mechanism in bilinguals relative to monolinguals (Bialystok, Craik, Green, & Gollan, 2009). This position predicts that in cases where one language does not need to be suppressed to use the other, no bilingual advantage should be observed. Indeed, in the case of bimodal bilinguals, who do not need to suppress their spoken languages while using a sign language, no cognitive advantage has been observed (Emmorey et al., 2008). Despite assumptions that consider linguistic control mechanisms as unique and totally different from other cognitive functions, most researchers argue that processes in effect during bilingual language selection are similar to those at play in task switching and other non-linguistic cognitive tasks (Meuter & Allport 1999; Paradis, 1980).

For years, the inhibition of the non-target language during language production had been the dominant account in explaining the bilingual advantage (Green, 1998; Philipp, Gade, & Koch, 2007). However, a recent comprehensive review maintains that bilingual cognitive advantages might best be understood in terms of enhancement to executive attention (Bialystok, 2017). In part of her argument, Bialystok states that attention is at the core of the executive function system, and that bilingual environments provide the basis for the development of a more flexible system of attention. Unlike theories focused on production, attentional advantages might be seen even in pre-verbal infants, a topic we will turn to in the next section.

Bilingual advantages in infancy

In contrast to traditional views which emphasize the role of sustained language production in the bilingual advantage, recent studies suggest a more general role of language processing. Under this scenario, the bilingual advantage would not necessarily be linked to production. This position is supported by studies reporting cognitive advantages in preverbal bilingual infants (Kovács & Mehler, 2009a; 2009b), and toddlers just starting to produce sentences (Poulin-Dubois et al., 2011). For example, Kovács and Mehler (2009a) compared the performance of 7-month-old monolingual and bilingual infants on an inhibition task in a series of eye-tracking experiments in which infants were presented with speech and visual cues. Each experiment consisted of nine training and nine test trials assessing infant's anticipatory eye movements. During training trials, infants saw a cue, followed by a visual reward on one side of the screen (a brightly coloured puppet, for example on the right side). After the offset of the cue and before the onset of the reward, there was a 1000-millisecond blank interval known as "anticipatory period". Infants were expected to learn that the cue predicted the reward and anticipate its appearance by looking towards the trained side (right) during the anticipatory period, before the reward appeared. At test, the reward switched sides (e.g., began appearing on the left). In sum, the reward always appeared on the same side of the screen during the training phase and on the other side during the test phase, and the side it appeared was counterbalanced across subjects. To successfully anticipate the reward at test, infants had to inhibit the previously learned response (e.g., looking right for the reward after seeing the cue) and produce a new response (e.g., looking left for the reward after seeing the cue). Results revealed that in all experiments, both monolinguals and bilinguals performed similarly during the training phase so that they all initially learned to anticipate the reward signaled by the cue. At test, however, it was only the bilinguals who displayed an increase in correct anticipatory looks during the test phase. They appeared to be better at suppressing the previously learned response and updating their predictions. This reveals that processing two languages from birth helps infants enhance their cognitive abilities even beyond the language domain. In an unpublished dissertation that attempted to replicate this effect, monolingual and bilingual infants aged 6 to 7 months were compared in an attentional switch task (Kakvan & Bialystok, 2017). Infants' anticipatory eye movements were measured on 30 trials of pre-switch and 30 trials of post-switch phases. Each trial consisted of two sections; First a visual cue (e.g., a circle) appeared in the middle of the screen signaling the appearance of a target stimulus on one side of the screen. Second, a different cue (e.g., a checkerboard) would appear followed by the target on the opposite side. Results revealed that bilingual infants, but not monolinguals, showed a significant increase in their anticipatory looks during the post-switch phase.

Evidence of a bilingual advantage has also been found at a slightly older age, 12 months, around the time that begin to produce their first words. Kovács and Mehler (2009b) exposed infants to two distinct syllabic structures; AAB (e.g. lo-lo-vu) and ABA (e.g., lo-vu-lo) associated with a reward on one side of the screen (e.g. AAB-right, ABA-left). Results revealed that while bilinguals were able to associate the structures with looking leftward and rightward, monolinguals could only do so with the simpler AAB structure. Authors concluded that bilingual infants were more flexible learners than their monolingual peers in handling inconsistent language inputs, and that this might be driven by enhanced cognitive control in bilinguals.

In another study, Poulin-Dubois and colleagues (2011) examined whether cognitive advantages in bilingual infants occur as they begin to speak. They tested a group of 24-month-olds on a battery of executive functioning tasks (Multilocation, Shape Stroop, Reverse Categorization, Snack Delay and Gift Delay). Results showed that monolingual and bilingual infants performed similarly on all tasks, except for the Shape Stroop task in which bilinguals outperformed monolinguals in inhibiting their prepotent response. The authors argued that their findings challenge previous accounts of bilingual advantage which merely emphasized the role of inhibition of the non-target language during production. Therefore, such an advantage seen among bilingual toddlers gives hints to other possible explanations for bilingual advantage beyond language production.

Studies that have used more naturalistic language stimuli also show evidence that bilingualism might enhance attention in infancy. For example, in one study infants were habituated to a series of silent speakers using either English or French, with the language switching at test. Results revealed that at 12 months, English-French bilinguals, but not monolinguals, were able to distinguish between languages by only relying on the visual cues (Weikum et al., 2007). The findings were replicated in a study with Spanish–Catalan bilinguals who saw a same video of switching between English and French (Sebastian-Galles et al., 2012). This study showed that bilinguals realized the language switch even if it happened in a language different from their native languages. Further evidence shows that 8 to 12-month-old monolinguals focus more on the eyes of an interlocutor, while bilinguals pay more attention to the mouth (Pons et al., 2015). All together, these findings suggest that bilingualism affects infants' developing attentional system. This may give them a precocious ability, which could generalize to control functions in other domains (Festman et al., 2010).

There is also some evidence that bilingual infants' cognitive advantages may extend to learning and memory. For example, 6-month-old bilinguals outperformed monolinguals in a basic visual habituation task, showing advantages in stimulus encoding and recognition memory (Brito & Barr, 2012; 2014; Singh et al., 2015). Further evidence for a bilingual advantage in memory tasks comes from a series of studies by Brito and colleagues. Brito and Barr (2012) examined whether being raised bilingual could help 18-month-old infants generalize across cues after a short delay. In a memory generalization task, infants saw a puppet performing three actions, and were later tested their performance of these actions with a novel puppet as a measure of memory generalization. Infants in a generalization group saw a puppet showing actions and were then encouraged to play with their own toys for half an hour. Infants in a baseline group just played with toys without observing the target actions. At test, a novel puppet was shown to infants in both groups, and they were encouraged to interact with it. Results revealed that infants in the baseline condition seldom performed the target actions with the puppet, which is not surprising as they had not seen these actions modeled before. However, in the experimental group bilinguals were more likely to perform the target actions than monolinguals, showing an advantage in memory generalization.

In a further attempt to examine at what age such an ability may emerge, Brito and Barr (2014) showed that 6-month-old bilingual infants generalized across cues significantly more than monolinguals. In a similar experiment, Brito et al., (2015) compared Spanish-Catalan and English-Spanish bilinguals to their monolingual counterparts at 18-months. Results replicated bilingual advantage in memory flexibility in both groups, while there was no significant difference between bilingual groups. The study had a second part in which infants' performance in the first experiment was compared to the performance of a group of trilingual infants. Result showed no advantage in memory flexibility for trilingual infants relative to the other two groups. All in all, these studies suggest that early experience with dual language systems may affect domain-general processes, such as flexibility in memory, that may enhance learning capacity.

The impact of language production on cognitive abilities

While studies showing advantages in pre-verbal bilingual infants rule out language production as the sole driver of these effects, other evidence from monolinguals suggests that vocabulary learning may nonetheless contribute to cognitive abilities. For example, there is some emerging evidence that shows that larger vocabulary size leads to better verbal prediction, which is then not just confined to language, and instead generalized to other cognitive domains. In monolingual infants, there is correlational evidence linking vocabulary size with cognitive control. Reuter et al. (2018) tested monolingual infants (12-24-month-old) with high and low productive vocabulary sizes in an eye tracking task using the anticipatory eye movement paradigm. The paradigm was similar to Kovács and Mehler (2009a; Experiment 3), in that infants saw a central visual cue predicting a visual reward on either the right or left side of the screen. Again, at test, the reward switched sides. Infants' anticipatory looks to the correct side at test were measured. Results showed that, independent of age, infants with larger vocabulary size made significantly more correct anticipations at test, after the target switched sides. Their findings suggest that language production may nevertheless be linked to cognitive control in infancy.

The potential link between cognitive control and language has been further supported in a recent study with 36- to 48-month-old monolinguals. It examined the effect of language production on verbal prediction (Brooks & Lew-Williams, under review) which is said to be generalized to other non-verbal cognitive domains. Infants were presented with pairs of familiar objects (e.g., apple, door) and listened to semantically constraining sentences that ended with either a congruent noun (e.g., I'm so hungry! I want to eat a yummy apple) or an incongruent noun (e.g., I'm so hungry! I want to eat a yummy door). They were expected to reorient their attention from the congruent to the incongruent stimulus following a prediction error. Results showed faster reorientation among children with larger spoken vocabularies suggesting that the ability to flexibly update predictions can benefit non-verbal prediction too. Furthermore, a longitudinal study showed that bilinguals who had a growth in their language proficiency (measured with an increase in the number of translation equivalents), over the course of 7 months, had enhanced executive functioning on conflict tasks (Crivello et al., 2016). The above-mentioned studies focused on one effect at a time, either vocabulary size (but in a monolingual sample) or bilingualism (but language proficiency instead of vocabulary size). However, it remains unclear how bilingualism and vocabulary size might either jointly or independently contribute to non-verbal prediction.

The present study

The question of whether and when bilingual infants show cognitive benefits is of central theoretical importance for understanding the developmental origins of and mechanisms underlying the bilingual advantage. However, nearly 10 years later, there are no published replications of Kovács and Mehler's (2009a) seminal work showing bilingual advantages in 7-month-olds. Unpublished replication attempts have yielded mixed evidence, with one study finding that bilingualism enhances young infants' inhibitory control (Kakvan & Bialystok, 2017), one showing bilinguals' slight tendency to show inhibition earlier (Ibánez-Lillo, Pons, Costa, & Sebastián-Gallés, 2010), and one other finding no relationship (Tsui & Fennell, 2018). Replicating and extending this finding is particularly crucial given more recent concerns about the replicability in psychological science in general (Simmons, 2011; Open Science Collaboration, 2015), and infancy research in particular (ManyBabies Consortium, 2017). The current research contributes to this direction by addressing two main questions. First, does bilingualism affect cognitive control before the onset of speech? Second, how does beginning to talk influence bilingual advantage in cognitive control? To address the first question, we compared 7-month-old monolingual infants with their bilingual counterparts on an anticipatory eye movement paradigm adapted from the study by Kovács and Mehler (2009a). For the second question, we compared 20-month-old monolingual and bilingual infants on the same task. Here, we examined how productive vocabulary, measured by vocabulary size using the MacArthur-Bates Communicative Developmental Inventory (MCDI), would impact performance on the task. The goal of the study was to find out the extent to which the bilingual advantage changes across infancy, from preverbal to verbal stage.

Experiment 1: 7-month-olds

Materials and Methods

Participants. Forty-one infants (M_{age} = 226 days, range: 204 – 250 days, girls = 23) were retained in the final sample. Twenty-one were monolingual (M_{age} = 225 days, range: 206 – 245 days, girls = 8), and heard their native language at least 90% of the time. Monolinguals came from French (*n* = 13) or English (*n* = 8) backgrounds. The other twenty infants were bilingual (M_{age} = 227 days, range: 204 – 250 days, girls = 15), hearing each of two languages between 25% and 75% of the time (Pearson, Fernandez, & Oller, 1993). Ten bilinguals were learning

English and French, and the other ten were learning different language pairs (see Table 1 for full details of participants' language backgrounds). Participants were recruited from government birth lists. They were all healthy full-term infants with no reported developmental, vision, hearing impairments. An additional 35 infants were excluded due to fussiness (n = 6), health issues (n = 5), failure to meet language criteria for being classified as monolingual or bilingual (n = 18), and technical issues with the eye-tracker (n = 6). An additional 29 infants were subsequently excluded from the final analysis due to lack of attention, which was defined as attending to fewer than half of the trials during either the training or the test phase.

We note that our rate of excluding participants from analysis may be somewhat higher than reported in previous studies, and this can be attributed to several reasons. First, some studies (e.g., Kovács & Mehler, 2009a) do not report exclusions, and thus we cannot know what their exclusion rate was. Second, other studies have used more lenient criteria for bilingualism (e.g., Crivello et al., 2016, who required 20% rather than our 25% exposure to the non-dominant language which was set prior to data collection), which would lower the exclusion rate. Finally, we used a strict criterion for attention (infants not attending to at least 5/9 trials in both the learning and test phases were excluded). Each of these decisions was made prior to data collection, which minimizes the possibility of questionable research practices such as *p*-hacking (Simmons, Nelson, & Simonsohn, 2011), but in this case may have led to higher exclusion rates than if decisions were made post-hoc.

Measures. To evaluate the amount of infants' exposure to different languages, we used the Multilingual Approach to Parent Language Estimates (MAPLE; Byers-Heinlein et al., under review) in conjunction with the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 2001). This is a semi-structured interview that asks parents about their family language background as well as the languages spoken directly to the child at home and in other environments such as daycare over the course of typical weekdays and weekends. Parents are walked through a typical day in the baby's life on weekdays and weekends across different periods of life since birth and estimate the number of hours their children hear one or more languages in direct interactions with others. At the end, the experimenter calculates the percentage of the time infants are exposed to each language.

Stimuli. Stimuli were created on the basis of those used by Kovács and Mehler (2009a) and Reuter et al. (2018), with the goal of creating a simple, visually-compelling, non-linguistic task. Visual stimuli consisted of simple geometric shapes which were a blue circle, two equally-sized white squares, and a picture of a brightly-colored butterfly. They were all selected from creativecommons.org. Auditory stimuli consisted of a whistle and a tinkling sound that were normalized to a standard hearing level of 70dB, and then combined with the visual stimuli to create videos using the Adobe Premiere Pro CC video editing software. Trials started with a central visual cue (the blue circle) displayed against a black background and flanked by two white squares on the right and left sides of the screen. The visual cue lasted for 2000 milliseconds. Accompanied by the whistle sound, it grew, then shrank and disappeared. After the offset of the cue, the anticipatory period lasting 1000 milliseconds began. Only the two white squares shown during this period. At the end of the anticipatory period, a visual reward (the butterfly) appeared inside either the left or the right square. The butterfly then spun in a circle for a period lasting 2000ms, accompanied by the tinkling sound. See Figure 1 for structure of the trial sequence.

Videos. Each infant saw 9 training and 9 test trials. During the training trials, the visual reward appeared consistently on one side of the screen (e.g., in the left white square), and during the test trials it switched sides (e.g. in the right white square). The side the reward appeared was counterbalanced across subjects, so that infants were randomly assigned to one of two experimental orders (e.g., right during training and left during test, or left during training and right during test).

Apparatus. The videos presented on a 24" Tobii T60XL corneal reflection eye tracker, and eye gaze data were collected with a sampling rate of 60 Hz using Tobii Studio Software.

Procedure. The study was approved by the Human Research Ethics Committee of Concordia University. Parents signed a consent form prior to the experiment and completed questionnaires either prior to or following the main part of the study. During the study, infants sat on their parent's lap on a chair in front of an eye tracker in a soundproof room. There was an approximate-60-cm distance between the infant's eye and the eye tracking monitor. Parents were asked to put on darkened sunglasses and headphones (which played music) so that they could not influence their infant's reactions. Also, they were instructed not to talk to their child during the study. Before the video was presented, there was a calibration stage during which Tobii calibrated the infant's eye based on a five-point infant calibration routine. Next, infants completed the 9 training and 9 test trials. The total duration of the experiment was approximately 1.5 minutes. At the end of the session, parents were thanked for their participation and children were presented with a small gift and an honorary diploma.

Results

The focus of the analysis was infants' anticipatory eye movements, that is, their attention to the two possible reward locations during the anticipatory period. We defined anticipatory eye movements as looks to either square where the reward could appear during the 1000 ms time window starting 150 ms after the offset of the cue and ending 150 ms after the onset of the reward (following Kovács &Mehler, 2009a; McMurray & Aslin, 2004). The 150ms offset was to account for the time necessary for infants to initiate an eye movement. Infants' looking was measured within areas of interest (AOI) around each square on both sides, and the circle in the middle, using a rectangle approximately 2 cm larger than the visual stimuli. Trials where the child looked for less than 500 ms in total to the three areas of interest during the window of analysis were excluded. Infants who were retained for the final analysis had looked for at least 500 ms or more in over 50% of trials (5 out of 9 trials) in both training and test phases.

Our main analyses followed Kovács and Mehler (2009a) as closely as possible. Two participants attended during at least 5 training and 5 test trials but failed to contribute data to all three of the blocks, and thus were excluded from analyses when necessary. Each trial was coded as either a correct anticipation, an incorrect anticipation, or no anticipation. Correct anticipations occurred when the infant looked longer into the white square where the reward would appear than to the other square. Incorrect anticipations occurred when the infant looked longer to the opposite square (e.g., where the reward would not appear) than to the correct square. No anticipations were recorded if the infant had zero looks to either squares and just focused on the area where the central circle had been. This is important because it suggested that infants were nonetheless attentive to the study, despite not making any anticipation. Trials were grouped in blocks of 3 (first/middle/last) in each of the two phases. A proportion correct anticipation score was calculated for infants on each of the three blocks of both the test and training phases, by dividing the number of trials with correct anticipations by the total number of trials with any type of anticipation (i.e., excluding trials with no anticipation). Figure 2 shows an illustration of results by language group (monolingual, bilingual) and phase.

Correct anticipations

Training. First, we analyzed infants' performance during the training phase, where we did not expect to see any monolingual-bilingual differences. A 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) mixed ANOVA showed no significant interaction, nor significant main effects of language or block (see Table 2 for full ANOVA results). The latter was surprising because we expected infants' performance to improve from the first to last block. To further test whether infants had learned the initial rule during the training phase, we did an additional analysis focusing on the first block of the test phase, rather than on the training phase. The rationale is that if infants have learned the initial rule, they might still show this pattern of responding initially at test. This would be evident if infants consistently looked to the wrong side (e.g., were below chance). Single sample t-tests were conducted for each language group separately to examine whether infants looked at the new target below chance (.5) on the first block of the test phase. Both monolingual and bilingual infants' performance were significantly below-chance on the first block of the test (Monolinguals, p = .0068; Bilinguals, p = .00072), (See Table 3 for mean values). Moreover, the two groups did not differ significantly from each other during this block, $t(39) = .59$, $p = .56$, suggesting that learning during training did occur, and was similar for both groups.

Test. A similar 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) mixed ANOVA was performed for the test phase. There was a significant main effect of block, $F(2,78) = 4.10$, $p = .0091$, but no main effect of language group or interaction of the block with language group (the full ANOVA results are presented in Table 4). Given that our central research question was about potential monolingual-bilingual differences, we nonetheless conducted one-way repeated measured ANOVA on each language group separately to further analyse whether each group's performance changed across blocks. Only bilinguals had a statistically significant main effect of block, $F(2,38) = 3.606$, $p = .036$, $\eta 2 = .046$, while for monolinguals the effect was marginally significant, $F(2,40) = 2.53$, $p = .092$, $\eta 2 = .042$. A series of paired samples t-tests were conducted for each group to compare performance across blocks. Monolinguals showed a marginally-significant improvement from the middle to last blocks (p =

.086), but other comparisons did not differ (*ps*> .10). Bilinguals had a near-significant improvement in performance from the first to the last block (p = .053), but other comparisons did not differ. Thus, both groups showed some evidence of improvement over the course of the test phase, but at different moments, (See Table 3 for mean values).

The results of the above analysis suggest that infants in both language groups inhibited their previous response to learn the new rule (that the target will not appear on the previous side), but there might be a difference in their speed of inhibition. To test this possibility, we conducted separate independent-samples t-tests comparing monolinguals and bilinguals at each of the three blocks. While there was no significant difference between the two groups at either first block (p = .60) and or last block (p = .19), bilinguals had more significant correct responses relative to monolinguals at middle block (p = .044), (See Table 3 for mean values). This suggests that although both groups performed similarly at the beginning at first block, bilinguals were faster in learning the new rule and updating their correct anticipations as they performed better at middle block, while monolinguals just started improving their responses from middle to last blocks.

Total anticipations

We also investigated whether monolinguals and bilinguals differed in the total frequency of their anticipations, whether correct or incorrect. This was important because if the ability to make correct anticipatory eye movements and inhibit the previously-learned response during test is assumed to be related to linguistic background, then the two language groups should not be different in their overall rate of making anticipations (whether correct or incorrect). As in the previous analysis, trials were grouped in blocks of 3 (first/middle/last) in the two phases. A 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) mixed ANOVA was performed for the training phase showing no main effect of language (p = .94), block (p = .085) or interaction of the two (p = .56). A 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) mixed ANOVA for the test phase also showed no main effect of language (p = .36), block (p = .25) and their interaction (p = .65). Therefore, the two language groups did not differ in their total frequency of anticipations, either during training or during test, which signals that the difference between the two groups' performance at training and test was only a function of linguistic background, not driven by their general ability of making overall anticipations.

Discussion

Experiment 1 examined whether being exposed to two languages from birth would lead to enhanced performance in an inhibitory control task at age 7 months. Our prediction was if bilingualism improves infants' cognitive control, bilingual infants would perform better than monolinguals at correctly anticipating the reward in the test phase which required executive control. However, in the training phase, the two groups were expected to perform similarly since no inhibitory control was required.

During training, neither groups of infants showed statistically significant improvement in their performance from the first to the last block, which was contrary to our expectations since this result did not provide reliable evidence for learning. However, further analysis of the first block of test trials suggested that both groups were performing significantly below chance. Below-chance performance suggests that infants were perseverating towards the previously-learned side, which would only be possible if they had learned the rule during the training phase. Overall, these results suggest that infants were able to learn the initial rule in the task, and that monolinguals and bilinguals did not differ in this basic ability.

Of more central importance was performance during the test phase. Both groups showed evidence for inhibitory control during the test phase, but also some differences. Specifically, while bilinguals improved from the first to the middle block, monolinguals' improvement occurred later from the second to the last block (note that both of these effects were marginally significant). Indeed, specifically during the middle block, but not during the other blocks, bilinguals' performance was statistically significantly better than monolinguals. Therefore, while the two groups were doing relatively similar in the first block, bilinguals had more correct anticipations in the middle block relative to monolinguals, which might suggest some tentative evidence for bilinguals' faster learning capacity compared to monolingual infants.

Overall, the bilingual advantage suggested in Experiment 1 is in line with previous studies showing a general benefit to attentional and cognitive system (Kovács & Mehler, 2009a) for crib bilinguals suggesting that processing inputs from two languages since birth engenders a more flexible cognitive system. Yet, the results of these studies are subtly different. In the study by Kovács and Mehler (2009a), infants showed that they had learned the initial rule by the last block of the training phase, while infants in our study showed learning after the last block of the training (by the first block of the test phase). Note that infants in both studies had equal opportunity to learn the rule (three blocks during the training phase), but infants in our study did not clearly demonstrate their learning until after the training phase was over. It is possible that our infants took slightly longer to learn the original rule than those in the study by Kovács and Mehler (2009a).

Also, Kovács and Mehler (2009a) reported a significant difference between monolinguals and bilinguals in the last block of test trials, while we observed a difference in the middle block that attenuated by the last block. This suggests that bilinguals in the two studies performed similarly, but that monolinguals in our study might have performed somewhat better than the monolinguals tested by Kovács and Mehler (2009a), although it is not clear why a difference in monolinguals would have been observed in the two studies. One reason could be the difference between the structure of our task between and the task devised by Kovács and Mehler (2009a). For instance, the cue in the study by Kovács and Mehler had a certain repetitive structure (for example, the visual cue was a series of objects in an AAB pattern) in the training, and a different repetitive structure (for example, an ABA pattern) in the test phase. In contrast, in our study the cue did not have any particular structure. Although studies show that infants and even newborns are able to discriminate these structures (Gervain et al., 2008), the structure of the task in the study by Kovács and Mehler might have made it more difficult for infants to accomplish it. Thus, our task, without having such structure, might have required less cognitive resources leading to better performance by monolinguals compared with monolinguals in the study by Kovács and Mehler. Nonetheless, our monolinguals' somewhat better performance could explain why the interaction between block and language group did not reach statistical significance in our study.

This result replicates the study by Kovács and Mehler (2009a) in part since there was no interaction of block with language group. One explanation could be the small sample size in this study. Furthermore, Kovács and Mehler (2009a) studied bilinguals who heard Italian with a number of other languages. In our study, however, bilinguals heard English and French, or English/French with another language. Being exposed to a different set of languages in the two studies might explain to some extent some of the differences between the two studies. For example, Green and Abutalebi (2013) suggest that bilingual advantages might be more robust for heterogeneous languages, although Bialystok (1999) report bilingual advantages in different language pairs (French-English, English-Chinese. The issue of different language pairs in infancy will need additional research.

Overall, results of Experiment 1 suggest an early-emerging cognitive advantage for bilingual infants in the preverbal stage. While these results suggest that the bilingual advantage at 7 months in this task is mostly replicable, questions remain regarding factors contributing to such bilingual advantage as infants move from the preverbal to the verbal stage. In Experiment 2, we focused on this question by examining the interaction of vocabulary size and bilingualism in the same task in 20-month-old infants.

Experiment 2: 20-month-olds

The goal of the second experiment was to understand the effect of language proficiency (measured by productive vocabulary size) on inhibitory control in monolinguals and bilinguals. The same design and procedure as in Experiment 1 were used testing 20-month-old monolingual and bilingual infants. The only difference was that a measure for estimating the vocabulary size was used for this group, as children of this age have started producing words.

Materials and Methods

Participants. Thirty-three infants (M_{age} = 627 days, range: 602 – 723 days, girls = 19) were included in the final sample. Twenty were monolinguals (M_{age} = 630 days, range: 603 – 723 days, girls = 13), and their native language was either French (*n* = 13) or English (*n* = 7). Thirteen were bilinguals (M_{age} = 624 days, range: 602 – 639 days, girls = 6), and the majority of these infants were exposed to English and French. Other language pairs are listed in Table 5. The same criteria were used for monolingualism and bilingualism as in Experiment 1. A total of 35 infants were excluded from analysis due to fussiness (*n* = 6), health issues (*n* = 2), failure to meet language criteria for being classified as monolingual or bilingual (*n* = 25), experimental error (*n* = 1) and parental intervention (*n* = 1). A further 24 infants were excluded for lack of attention, which was defined as in Experiment 1.

Measures. In addition to the Language Exposure Questionnaire completed in Experiment 1, parents in this Experiment also completed measures of children's vocabulary size. Vocabulary was assessed using the MacArthur-Bates Communicative Developmental Inventory (MCDI) for English words (Fenson et al., 1993), and its adaptation in Québec French (Trudeau, Frank, &

Poulin-Dubois, 1999). Parents of monolinguals completed one MCDI in their child's native language, and parents of bilinguals completed two MCDIs corresponding to the two languages their children were acquiring so that vocabulary size across the two languages could be computed. For bilinguals, there are several ways to combine vocabulary size across the languages. Total vocabulary size is the sum of the all words that children produce across all their languages. Conceptual vocabulary size which is a child's total vocabulary size after excluding translation equivalents (Pearson et al., 1993). Translation equivalents are words that bilingual children acquire in each of their languages for the same concept, for example *dog* in English and *chien* in French (Legacy, Zesiger, Friend & Poulin-Dubois, 2015). Given research suggesting that total conceptual vocabulary size in bilinguals is most comparable to vocabulary size in monolinguals (Pearson et al., 1993, although see Core et al., 2013), we focused on this measure in the current study.

Procedure. Experiment 2 employed the same procedure as in Experiment 1.

Results

The analysis for Experiment 2 used the same AOIs, window of analysis, and exclusion criteria as in Experiment 1. Further, as infants were older, we could also examine the effect of infant's vocabulary size on making correct anticipations. To evaluate this, we compared high-vocabulary and low-vocabulary groups of infants, based on a median split within each group for conceptual vocabulary (MCDI) scores. Three participants, whose second language was other than French and English, were excluded from this analysis because complete MCDI data could not be obtained. Monolinguals (*Med* = 76) and bilinguals (*Med* = 88) had similar median vocabulary scores. Once again, a proportion of correct anticipation score was calculated for infants on each trial of test and training phases. Five participants did not contribute data during all blocks of the test phase, even though they had contributed a total of 5 or more trials and were excluded where their missing data prevented analysis. Figure 3 shows an illustration of results by language group (monolingual, bilingual), vocabulary size (high vs low), and phase.

Correct anticipations

Training. To examine infant's performance during the training phase, a 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) x 2 (vocabulary size: high, low) mixed ANOVA was conducted. There was a significant main effect of block, but no other significant effects or interactions suggesting that learning was similar for monolinguals and bilinguals, and across vocabulary groups (See Table 6 for all main effects and interactions). To examine the effect of block, we performed paired t-tests comparing blocks to each other, collapsing across vocabulary size and language group. There was a significant improvement from first to middle block ($p = .015$), but then a significant decrement in performance between the middle to last block ($p = .015$). There was no significant difference between the first and last blocks ($p = .76$). This suggests that while infants were learning fast from the beginning to the mid trials, they may have begun disengaging from the task towards the end of the learning phase.

Although the main effect of vocabulary size during training was not statistically significant, given our original hypothesis, we nonetheless decided to further investigate potential effects. We had originally anticipated doing so separately for monolinguals and bilinguals, but instead collapsed across language groups due to small cell sizes (only five infants in some cases). An independent t-test on vocabulary group (high vs. low) showed that infants with low vocabulary size had marginally significant more correct anticipations relative to infants with high vocabulary size, $t(88) = -1.84$, $p = .069$, (See Table 7 for means of the training phase). This was opposite to our hypothesis that infants with high vocabulary would have more correct anticipations.

Test. Next, we examined performance during the test phase, with a similar 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) x 2 (vocabulary size: high, low) mixed ANOVA (See Table 8 for all main effects and interactions). There was a main effect of vocabulary size, with the low vocabulary infants again having marginally more correct inhibitory looks relative to the high vocabulary infants. There was no significant effect of language group, block, or interaction between the factors. Given our main research question concerning the role of bilingualism, we did additional analyses to examine whether monolinguals and bilinguals were learning to inhibit their previously learned response. Single sample *t*-tests were conducted to examine infants' anticipatory looks at test phase. Bilinguals' performance during test was significantly above chance at middle block ($p = .022$), but not at the first block or the last block. Monolinguals' performance during test was not significantly different from chance during any of the blocks ($ps > .05$), (See Table 9 for means of the test phase).

Again, although we had planned to do follow-up tests examining high vocabulary and low vocabulary subsets of monolinguals and bilinguals separately, small samples sizes in these cells (only five infants in some cases) prevented doing this analysis. Thus, as for training, we pooled data during test trials from monolinguals and bilinguals to investigate the overall effects of vocabulary size. An independent *t*-test showed that the low vocabulary infants had marginally more correct inhibitory looks relative to the high vocabulary infants, t (73) = -1.804, p = .075, consistent with the effect observed in the ANOVA. Overall, these analyses indicate that bilingualism and vocabulary size may both affect 20-month-olds' performance in this task. Children with low vocabulary size, and to some degree bilingual infants, showed better performance at test in this task.

Total anticipations

An important question is whether the effects observed for infant's correct anticipations could be driven by overall tendencies to make any anticipations, whether correct or incorrect. Thus, this analysis investigated whether infants differed in the total frequency of their anticipations (correct and incorrect). As in the previous analysis, trials were grouped in blocks of 3 (first/middle/last) in the two phases (training and test).

Training. A 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) x 2 (vocabulary size: high, low) mixed ANOVA was performed for the training phase. There was a significant main effect of block $F(2,52) = 4.98$, $p = .010$, a marginally significant effect of vocabulary size $F(1,26) = 3.28$, $p = .081$, but no significant effect of language $F(1,26) = .012$, $p = .91$. Effects were non-significant for all interactions: language and vocabulary size $F(1,26) = .14$, $p = .71$, language and block $F(2,52) = .45$, $p = .64$, vocabulary size and block $F(2,52) = .67$, $p = .52$, and overall three-way interaction of language, vocabulary size and block $F(2,52) = .72$, $p = .49$. To examine the effect of block, we performed paired *t*-tests comparing blocks to each other, collapsing across vocabulary size and language group. There was a non-significant improvement from first to middle block ($M_{block1} = .82$ vs $M_{block2} = .91$, $p = .18$), but then a significant decrement in performance between the middle to last block ($M_{block3} = .71$, $p = .0082$), and no significant difference between the first and last blocks ($p = .18$). Moreover, collapsing across blocks, an independent *t*-test showed that infants with low vocabulary size had marginally significant more overall anticipations ($M = .87$) relative to infants with high vocabulary size (M

= .75), $t(88) = -2.072$, $p = .041$. This suggests that while infants increased the number of anticipations from the beginning to the mid trials, they may have begun disengaging from the task towards the end of the training phase. Moreover, infants with low vocabulary size appeared to have been more engaged in the task during training than those with high vocabulary size, given they produced more total anticipations.

Test. To investigate whether groups were different in their total anticipations during the test phase, a 2 (language group: monolinguals, bilinguals) x 3 (block: first, middle, last) x 2 (vocabulary size: high, low) mixed ANOVA was performed. There was a marginally significant effect of block $F(2,42) = 2.89$, $p = .066$, but there were no main effects of language $F(1,21) = .17$, $p = .68$, or vocabulary size $F(1,21) = .29$, $p = .59$. None of the interactions were significant: language and vocabulary size $F(1,21) = .47$, $p = .50$, language and block $F(2,42) = 2.02$, $p = .14$, vocabulary size and block $F(2,42) = .092$, $p = .91$, the three-way interaction of language, vocabulary size and block $F(2,42) = .25$, $p = .78$. To further examine the main effect of block, we performed paired *t*-tests comparing blocks to each other, collapsing across vocabulary size and language group. There was a significant decrement from first to middle block ($M_{\text{block1}} = .95$ vs $M_{\text{block2}} = .74$, $p = .028$), no significant change between the middle and last block ($M_{\text{block3}} = .79$, $p = .58$), and a significant decrement between the first and last blocks ($p = .028$). Moreover, collapsing across blocks, an independent t-test showed that infants with low vocabulary size had slightly more overall anticipations ($M = .84$) relative to infants with high vocabulary size ($M = .81$), although the difference was not statistically significant, $t(73) = -.46 =$, $p = .65$. This suggests that infants were disengaging from the task on a faster rate compared to the training phase since by middle block they had a significant decrement in their overall anticipations.

Discussion

Experiment 2 examined whether vocabulary size in older infants would interact with bilingualism in their inhibitory control. We expected to once again observe an advantage for bilingual infants, as well as an advantage for infants with larger vocabularies at test. However, at training, infants were expected to perform similarly since no inhibitory control was required.

Our main hypothesis concerned the effects of bilingualism on cognitive control. Monolingual and bilingual infants showed similar learning behavior in the training phase. Infants showed an improvement in performance from the first to middle block, suggesting that they learned the initial rule. At test, we observed a possible bilingual advantage in learning to inhibit the previously learned response and updating predictions. This was not due to differences in the overall number of anticipations produced by monolinguals and bilinguals. Monolingual infants did not show above-chance performance in any of the blocks, but bilingual infants were above chance at middle block of the test. Although this effect was not particularly strong, it suggested some tentative evidence of bilingual advantage in inhibitory control. As the test became more challenging – requiring inhibition of previous response – a more enhanced cognitive capacity was required. This finding was in line with similar studies showing that receiving variable input by bilingual leaners leads to an increase in the frequency of updating information (Bialystok, 2017). This applies to bilinguals, who have the opportunity of receiving input from two languages since birth. Therefore, being exposed to two languages may have enabled bilingual infants to better exert inhibitory control during the test phase. Another potential explanation of the bilingual advantage is that the experience of being exposed to a second language, which requires bilinguals to switch attention between their two language systems, led to more flexibility in their general attentional system and helped them perform better at test. While we were originally interested in potential interactions between vocabulary size and bilingualism, small cell sizes prevented this analysis.

The results concerning vocabulary size are somewhat more challenging to interpret. We found a pattern where infants with smaller vocabulary sizes showed more correct anticipatory looks at test than those with larger vocabularies. One possible explanation is that low vocabulary children learned faster than high vocabulary children for some reason. However, this is completely opposite to what has been reported in previous work with monolingual infants using a similar paradigm, which found that infants with larger vocabularies performed better than those with smaller vocabularies (Reuter et al., 2018). This finding had been interpreted in the context of other previous studies showing that children with larger vocabularies, relative to those with smaller vocabularies, are more likely to make successful verbal predictions (Nation, Marshall, & Altmann, 2003; Mani & Huettig, 2012). Thus, our findings stand in contrast to a large body of previous work.

A more likely explanation might be that the low-vocabulary infants engaged more with the task while high vocabulary infants disengaged more quickly as they learned the task faster. It is important to note that while low vocabulary infants had more correct anticipations, they also had more total anticipations, especially during training. One explanation for this could be due to differences in the allocation of attentional resources to repeated presentations of stimuli. A related previous study with 20-month-old infants shows that when presented with novel stimuli, infants with higher vocabulary size relative to their peers with low vocabulary size learned faster and after fewer repetitions of the novel stimuli (Koss Torkildsen et al., 2009). Similarly, in our task, it may be that infants with larger vocabularies were able to more appropriately allocate their attention to the stimuli, thus they would faster learn the rule of the study and more rapidly disengage from the task, while infants with low vocabulary size attended to the task for more trials as they found it more challenging. Future studies might explore the use of an infant-controlled paradigm to equate the task for different learners.

Other evidence also suggests that at 20 months, this task might be overly simple for some infants. During both training and test, the pattern of performance that we observed is similar to a previously-reported inverted u-shape, according to which when infants are presented with novel stimuli which repeats itself, their looking time first rises, as they become more familiar with the stimuli it reaches a turning point, and diminishes with further repetition (Roder, Bushnell & Sasseville, 2000). In a similar pattern, both monolingual and bilingual infants in our study had low performance in the first block, nearly reached a ceiling effect toward the middle block, and then had a decline in performance toward the end of the task. All infants appeared to disengage to some degree by the end of the task, but perhaps some groups more than others.

Yet, this still raises the question of why Reuter et al. (2018) observed that higher vocabulary infants performed more correct anticipations, while we found that they performed fewer. One reason could be that while we specifically tested 20-month-olds, Reuter et al. (2018) tested infants spanning from 12-24 months. Thus, many of the infants in their study were younger than those in our study, and they might have been more attentive to the task. Overall, our results suggest that this task might be less appropriate for infants by 20 months.

To conclude, bilingual infants showed some tentative evidence of better cognitive performance at test. While we were interested in the interactions of bilingualism and vocabulary size, we could not further investigate this effect due to small cell sizes. Our vocabulary size results – in which low vocabulary size infants performed more correct and total anticipations than low-vocabulary size infants – appear to have been driven by this task being not sufficiently engaging for some infants at this age.

General Discussion

The main goal of this research was to understand how bilingualism and vocabulary size enhance infants' cognitive control. We conducted two studies using an anticipatory eye movement paradigm. Experiment 1 compared 7-month-old monolingual and bilingual infants, who had not yet started speaking, to address the question of how bilingualism affects cognitive control before the onset of speech. Experiment 2 addressed the question of how beginning to build a vocabulary influences the bilingual advantage in cognitive control. Here, we were interested to look at the trajectory of bilingual advantage in older bilinguals, and we compared 20-month-old monolingual and bilingual infants with high and low vocabulary size. Results showed that bilingualism enhances cognitive control both at 7 and 20 months. There were also differences between high and low vocabulary infants in performance at 20 months.

In Experiment 1, we aimed to replicate an important study reporting cognitive control advantage in preverbal bilingual infants (Kovács & Mehler, 2009a). This was of high importance due to speculations regarding the replicability of this and other studies (Brito & Barr, 2012; Singh et al., 2015) reporting the positive effects of bilingualism on infants' cognitive system. Results of Experiment 1 showed some provisional evidence for a bilingual advantage by 7 months which to some extent replicated the study by Kovács and Mehler (2009a) suggesting that processing inputs from two languages since birth might lead to a more flexible cognitive system. However, the bilingual advantage in this study was not as strong as the effect found by Kovács and Mehler (2009a) since there were subtle differences in methodology between the two studies, and also monolinguals in our research showed better performance than those in the study by Kovács and Mehler (2009a), attenuating monolingual-bilingual differences.

In Experiment 2, we examined the trajectory of bilingual advantage as infants become older and produce their first words. This question was addressed by infants in Experiment 2 who were 20 months old and thus were nearly one year older than 7-month-olds in Experiment 1. It was important to test older infants, as they undergo developments not only in their general cognitive and attentional system that occur during the first year of life (Colombo & Cheatham, 2006), but they also in their linguistic abilities. We used the same task as in Experiment 1, and also examined the effect of vocabulary size as one potential factor contributing to better inhibitory control in non-verbal tasks (Reuter et al., 2018). Results showed that there was a possible effect of vocabulary size during training and test suggesting that low vocabulary infants showed better overall performance, while at test only there was some tentative evidence of bilingual advantage. While we were originally interested in potential interactions between bilingualism and vocabulary size, a small sample size prevented us from further investigation of the interaction of the two effects. The finding that infants with lower vocabulary sizes performed better was surprising, and opposite to previously-reported results (Reuter et al., 2018). It may be that our task was somewhat too easy for 20-month-old infants, resulting in more advanced (i.e. higher vocabulary size) learners to disengage, lowering their overall performance scores. This interpretation is supported by a finding that high vocabulary children produced fewer total anticipations (whether correct or incorrect) than low vocabulary children, particularly during training.

A comparison of the findings from the two experiments show that while a bilingual advantage was observed among preverbal infants, the effect was not as apparent at 20 months. This could be because, while the cognitive task we designed for this research was appropriate for 7-month-old infants, it was less suitable for older infants at 20 months. Given the cognitive and linguistic development that infants undergo from the preverbal to verbal stage, it seems challenging to find an appropriate task which could be suitable for both age groups and would enable us to fully examine the trajectory of changes form the preverbal to the verbal stage. A modification that reduced the number of trials in the training and test phase might be appropriate, given evidence that 20-month-olds' attention waned during the last 3 trials of each phase. Another option would be an infant-controlled task. The other limitation of the current study, other than the design of the task, was the small sample size which prevented further investigation of the interaction of the effect of bilingualism and vocabulary size in older infants. However, data collection is ongoing for Experiment 2 to enable us to examine such interactions in the future.

All in all, the findings from this study suggest a subtle effect of bilingual advantage in cognitive control which emerges by 7 months and is maintained at 20 months. The bilingual effect we found in this research to some extent replicates findings from the highly-cited study by

Kovács and Mehler (2009a) indicating that the early-emerging bilingual advantage is not just limited to language production (as in 20-month-olds); rather it can occur before the onset of speech as we observed in our 7-month-old infants. As Kovács and Mehler (2009a) put, processing representations from two languages leads to an enhanced cognitive control system. This is contrary to traditional approaches claiming that bilingual advantage stemmed from constant productive experience with two languages. Traditionally it was assumed that when bilinguals are speaking one language, both languages are available and activated (Green, 1998; Chee, 2006), but the unused language must be suppressed. Therefore, managing the conflict from the simultaneous activation of the two languages was the key factor for explaining the emergence of bilingual advantage. According to this account, the conflict management that bilinguals experienced in everyday language production could be generalized to domains outside the domain of language giving bilinguals a more advanced system of executive functions. However, our results from 7-month-olds indicate a bilingual advantage in tasks with preverbal infants. Given that 7-month-olds do not yet produce words, this suggests that language conflict management at preverbal stage could happen while bilinguals listen to their both languages (for a discussion, see Byers-Heinlein, Morin-Lessard, & Lew-Williams, 2017).

Results with 20-month-olds also indicated a potential bilingual advantage at this age. While these infants have begun producing language, their production abilities are much more limited than adults', and it is unclear how much they would be inhibiting one language to speak the other. This is similar to what has been reported in a related study of 24-month-old infants who were tested on a large battery of executive functioning tasks. Results showed bilingual advantage only in an inhibition task (Shape Stroop) and not in other tasks (Poulin-Dubois et al., 2011). Again, although infants were in the verbal stage at this age, they had much less experience in language production. One interesting direction for future research would be to examine individual differences in cognitive control within bilingual infants. For example, Crivello et al., (2016) found a link between growth in knowledge of translation equivalents (cross-language synonyms) and bilingual toddler's executive function. Such an analysis is not possible for the current data, as we do not have data on this measure given that vocabulary size was only measured at a single time point. Nonetheless, future studies may clarify if growth in representations from two languages can improve bilinguals' cognitive control performance.

Thus far in this thesis, the bilingual advantage has been characterized in several ways: as a cognitive advantage, increased flexibility, or enhanced inhibitory control. While most traditional accounts have focused on inhibitory control necessary in producing one language rather than another, results from infant studies suggest that this may not be the only or best way to characterize the bilingual advantage. Executive functioning is a broad umbrella term for cognitive components such as inhibition, working memory and shifting (Miyake & Friedman, 2012). It still remains unclear which component or components of executive functioning are enhanced from bilingual language processing.

Many accounts have proposed that inhibition is the reason behind bilingual advantages because as mentioned above, when bilinguals use one language, the other language is supressed or inhibited to avoid interference between the two language systems (Miyake et al., 2000). However, one cannot for sure confirm which of these components are responsible for developmental differences in bilinguals as there is no clear evidence available. For instance, Bialystok (2015) argues that while bilingual advantage has been observed in several tasks which require inhibition (such as flanker task), there are other tasks which require no inhibition (e.g., congruent trials; Bialystok, 2010) or some types of inhibition (e.g., response inhibition tasks versus cognitive inhibition; Carlson & Meltzoff, 2008) but still showing bilingual advantage. Also, some studies suggest that monitoring is the source of bilingual advantage instead of inhibition (Hilchey & Klein, 2011). Monitoring, which includes inhibition to some extent, takes place when subjects have to ignore the previous stimuli or rule of the study (for example, anticipating the target on left side of the screen), and shift their attention to newly relevant rule (for example, anticipating the target on left side of the screen).

All together, different studies point to different components of executive functioning being enhanced in bilinguals. However, due to lack of consensus for responsibility of one specific component of executive functions in bilingual advantage, the link between differences in bilingual development and cognitive advantages is still unclear. In infancy, it is particularly challenging to design tasks that clearly tap into one component of executive function and not others.

One way to solve this problem, instead of focusing on one aspect of executive functions, is to examine what factors trigger differences in information processing that leads to enhanced executive functions in bilinguals relative to monolinguals. One possibility is that bilingualism alters the way attention is directed to the environment (Bialystok, 2015). Support for this idea comes from studies in which infants were habituated to a series of silent speakers using two languages which switched at test. Results revealed that only bilingual infants distinguished between languages by only relying on the visual cues (Weikum et al., 2007). The same happened when the two languages were completely different from those heard by the bilingual infants (Sebastian-Galles et al., 2012). The findings from these studies argue that mere exposure to two linguistic environments confer upon bilingual advantages in cognitive processing. Thus, bilingual environments expose infants to two sets of sounds, speakers and facial configurations, which draws infants' attention to contrasts between the two systems, and consequently such contrast creates more novelty requiring bilinguals to pay more attention to stimuli and detect subtle changes in the environment. Therefore, bilinguals might have a more complex representational system that has to make a balance between their two languages. Here, rather than inhibiting the non-target language, executive functions are deployed to maintain attention to the target language. Thus, it may be that a more unified system of executive functions is developed in bilinguals (Bialystok, 2015).

In a similar account, Kakvan and Bialystok (2017) proposed that better performance of bilinguals in an anticipatory eye movement task, similar to our task, might be indicative of a more efficient attentional processing which requires attentional switch at test phase. The authors suggest that during test phase, infants have to unlearn what they already have learned, and this requires allocation of attention to the new target location. Also, according to Grossberg's attentional model (Grossberg, 1975), when infants encounter novel and unexpected stimuli (as they would in moving from the training to the test phase of our task), they will have an increase in allocating their attentional resources in order to put aside previous expectations and update the novel information. Altogether, processing representations from two languages since birth might enable bilinguals to develop a more efficient attentional system which is more adaptive to changes in the environment.

Overall, our results replicate previous results showing that processing two languages from birth enables both preverbal and to some extent verbal infants to enhance their cognitive capacity. The effects of vocabulary size are more challenging to measure at 20 months, as vocabulary size appears to influence infants' willingness to perform our task. Although our current sample did not allow an analysis of the interaction of the effects of bilingualism and vocabulary size, we found a tentative effect of vocabulary size where infants with high vocabulary infants disengaged faster from the task. Future studies may provide a basis for a better investigation of the interaction of the two effects.

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Table 1

Language pairs spoken to bilinguals in Experiment 1 (7-month-olds)

Participants	Dominant Language%		Non-Dominant Language%		Third Language%	
1	Russian	73	English	27		
2	Spanish	72	English	28		
3	Italian	59	English	36	French	5
4	English	69	Spanish	25	French	6
5	Serbian	51	English	37	French	12
6	Arabic	56	English	27	French	17
7	English	66	French	25	Korean	9
8	English	75	French	25		
9	English	75	French	25		
10	English	73	French	27		
11	French	39	Spanish	32	English	29
12	English	45	French	40	Greek	15
13	English	58	French	42		
14	Kabyle	53	French	47		
15	French	54	English	46		
16	French	59	Creole	36	English	5
17	French	60	Romanian	40		
18	French	61	English	28	Creole	11
19	French	65	English	35		
20	French	71	English	29		

Table 2

Mixed ANOVA results for the training phase in Experiment 1 (7-month-olds)

Source	*df*	SS	MS	*F*	*p*	*η2*
Language	37	11.19	.30	1.57	0.22	0.026
Blocks number	74	5.99	.081	1.29	0.28	0.012
Language x Blocks number	74	5.99	.081	1.06	0.35	0.0099

Table 3

Means and Standard Deviations on the measure of anticipations at each block of training and test as function of language group in Experiment 1 (7-month-olds)

		Training		Test	
Language group	Blocks	*M*	*SD*	*M*	*SD*
Monolinguals	First	0.533	0.361	0.182	0.364
	Middle	0.608	0.379	0.119	0.312
	Last	0.600	0.427	0.293	0.368
Bilinguals	First	0.429	0.427	0.250	0.368
	Middle	0.377	0.346	0.350	0.396
	Last	0.552	0.412	0.458	0.414

Table 4

Mixed ANOVA results for the test phase in Experiment 1 (7-month-olds)

Source	*df*	SS	MS	*F*	*p*	*η2*
Language	39	11.29	.29	2.53	.12	.043
Blocks number	78	4.89	.063	4.10	.0091*	.037
Language x Blocks number	78	4.89	.063	1.11	.34	.0085

Note. * p < .05

Table 5

Language pairs spoken by bilinguals in Experiment 2 (20-month-olds)

Participants	Dominant Language	%	Non-Dominant Language	%	Third Language	%
1	English	35	French	34	Spanish	31
2	English	59	French	30	Korean	11
3	English	69	French	31		
4	English	59	French	41		
5	English	55	French	45		
6	English	50	French	50		
7	English	51	French	49		
8	French	48	English	41	Italian	11
9	French	73	English	27		
10	French	67	English	33		
11	French	69	Farsi	31		
12	French	60	Spanish	33	English	7
13	Kabyle	61	French	39		

Table 6

Mixed ANOVA results for the training phase in Experiment 2 (20-month-olds)

Source	*df*	SS	MS	*F*	*p*	*η2*
Language	26	3.808	0.15	0.23	0.63	0.004
Vocabulary size	26	3.808	0.15	2.76	0.11	0.045
Blocks number	52	4.622	0.088	4.13	0.021*	0.080
Language x Vocabulary size	26	3.808	0.15	0.17	0.68	0.003
Language x Blocks number	52	4.622	0.088	0.29	0.75	0.006
Vocabulary size x Blocks number	52	4.622	0.088	0.26	0.77	0.005
Language x Vocabulary size x Blocks	52	4.622	0.088	1.95	0.15	0.039

Note. * $p < .05$

Table 7

Means and Standard Deviations in the training phase of Experiment 2 (20-month-olds)

		Monolinguals		Bilinguals	
Vocabulary size	Blocks	*M*	*SD*	*M*	*SD*
Low	First	0.79	.26	0.53	.30
	Middle	0.88	.24	1.00	.00
	Last	0.66	.44	0.80	.45
High	First	0.56	.42	0.60	.28
	Middle	0.81	.22	0.66	.33
	Last	0.65	.37	0.53	.30

Table 8

Mixed ANOVA results for the test phase in Experiment 2 (20-month-olds)

Source	*df*	SS	MS	*F*	*p*	*η2*
Language	21	2.826	.134	1.29	.27	0.018
Vocabulary size	21	2.826	.134	4.36	.049*	0.060
Blocks number	42	6.252	.148	1.66	.20	0.051
Language x Vocabulary size	21	2.826	.134	2.26	.15	0.032
Language x Blocks number	42	6.252	.148	.85	.43	0.027
Vocabulary size x Blocks number	42	6.252	.148	.69	.51	0.022
Language x Vocabulary size x Blocks number	42	6.252	.148	.24	.79	0.007

Note. * $p < .05$

Table 9

Means and Standard Deviations in the test phase of Experiment 2 (20-month-olds)

		Monolinguals		Bilinguals	
Vocabulary size	Blocks	*M*	*SD*	*M*	*SD*
Low	First	0.35	.40	0.50	.29
	Middle	0.48	.43	0.93	.15
	Last	0.70	.42	0.80	.27
High	First	0.40	.25	0.40	.28
	Middle	0.60	.47	0.57	.28
	Last	0.52	.39	0.33	.41

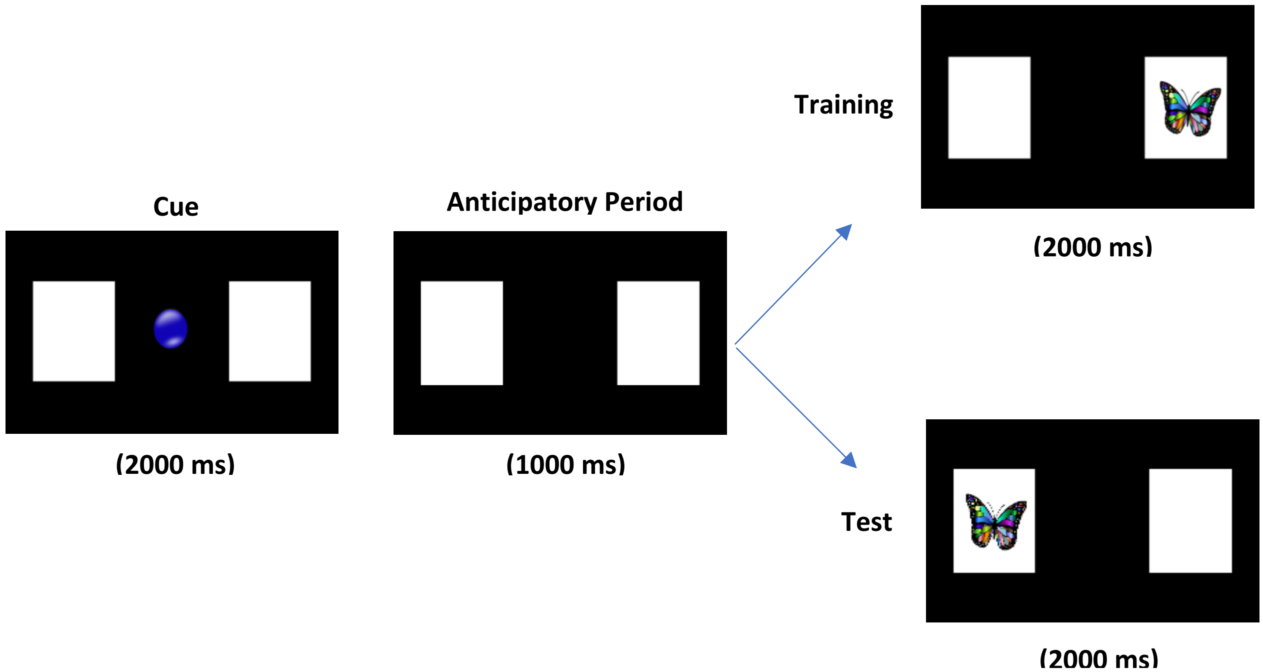

Figure 1. Structure of the trial sequence. Trials started with a fixation display of a central visual cue (a blue circle) against a black background and flanked by two white squares on the right and left sides of the screen. The anticipatory period began after the offset of the cue, where only the white squares were visible. At the end of the anticipatory period, a visual reward (a butterfly) appeared inside either the left or the right square. It was always displayed inside the same square during the training phase (9 trials) and in the other square during the test phase (9 trials).

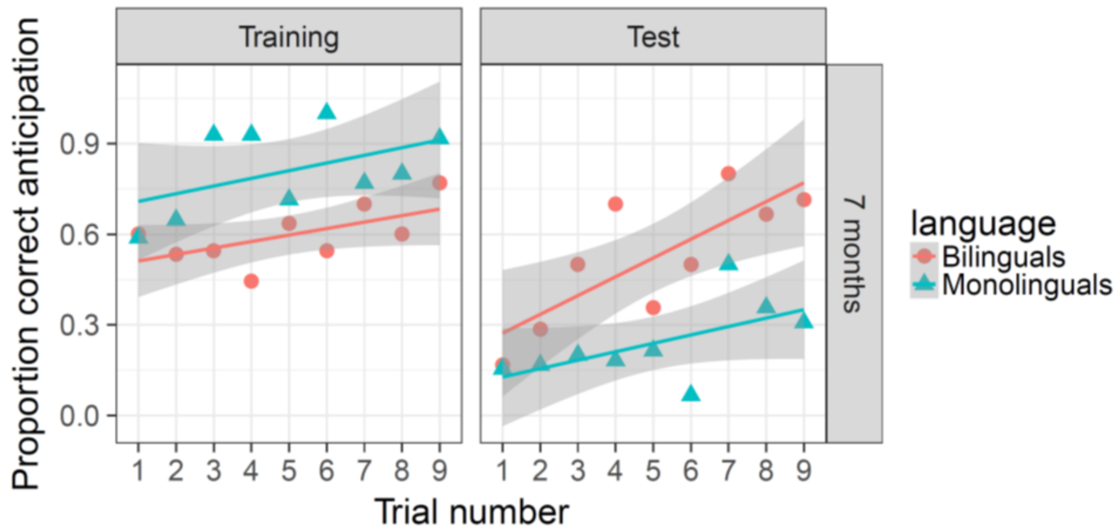

Figure 2. Results of Experiment 1. Symbols represent the proportion of infants with correct anticipatory looks. Green triangles represent population averages of monolingual infants, and orange dots represent averages for bilinguals. Linear regression lines with confidence intervals are shown for both groups.

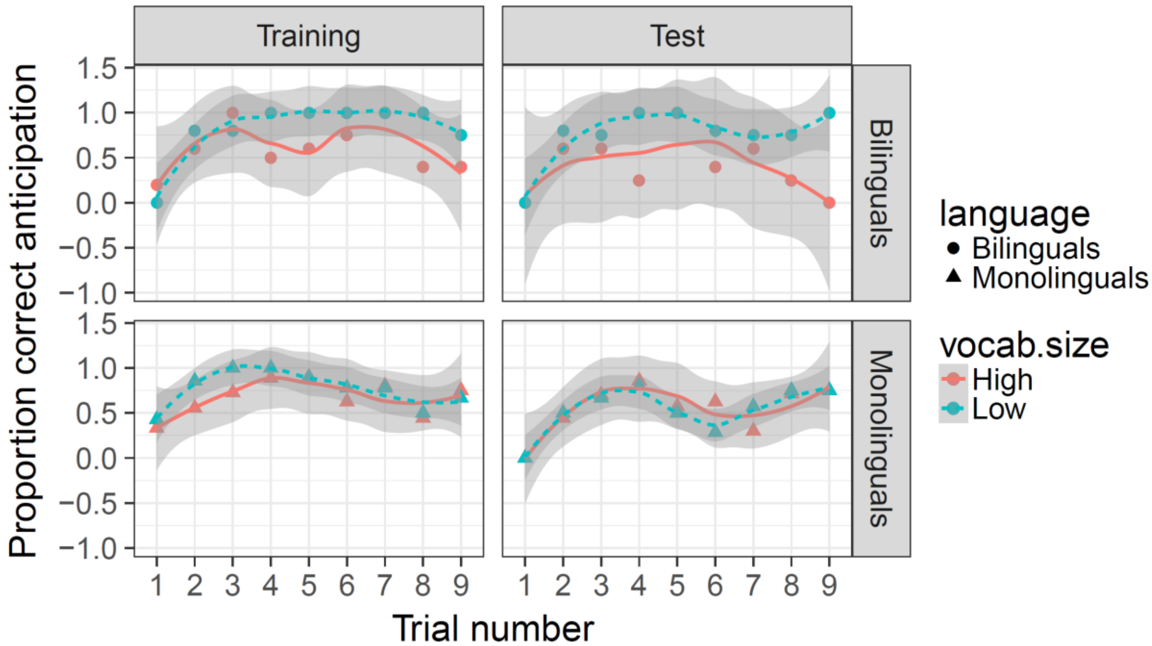

Figure 3. Results of Experiment 2. Symbols represent the proportion of infants with correct anticipatory looks. Dots represent averages for bilingual infants, and triangles represent averages for monolinguals. Linear regression lines with confidence intervals are shown for both groups. Thick orange lines represent infants with higher vocabulary size and dotted green lines represent infants with low vocabulary size.