

The impact of bilingual environments on selective attention in infancy

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Abstract

Bilingualism has been observed to influence cognitive processing across the lifespan but whether bilingual environments have an effect on selective attention and attention strategies in infancy remains an unresolved question. In Study 1, infants exposed to monolingual or bilingual environments participated in an eye-tracking cueing task in which they saw centrally presented stimuli followed by a target appearing on either the left or right side of the screen. Halfway through the trials, the central stimuli reliably predicted targets' locations. In Study 2, the first half of the trials consisted of centrally presented cues that predicted targets' locations; in the second half, the cue–target location relation switched. All infants performed similarly in Study 1, but in Study 2 infants raised in bilingual, but not monolingual, environments were able to successfully update their expectations by making more correct anticipatory eye movements to the target and expressing faster reactive eye latencies toward the target in the post-switch condition. The experience of attending to a complex environment in which infants simultaneously process and contrast two languages may account for why infants raised in bilingual environments have greater attentional control than those raised in monolingual environments.

KEYWORDS

attention, bilingualism, cognitive development, eye-tracking, infancy, visual expectations

1 | INTRODUCTION

Bilingualism has been shown to impact cognitive processing across the lifespan, with the primary effects found in improvements to executive function (review in Bialystok, 2017). In these studies, standard measures of executive function, such as flanker tasks and Simon tasks, are performed better by bilingual children (e.g., Grundy & Keyvani Chahi, 2017; Poarch & Van Hell, 2012; Yang, Yang, & Lust, 2011) and older adults (e.g., Bialystok, Poarch, Luo, & Craik, 2014; Gold, Kim, Johnson, Kryscio, & Smith, 2013; Salvatierra & Rosselli, 2011) than by their monolingual counterparts. These behavioral differences in executive function performance, however, are rarely found in young adults (e.g., Bialystok, Martin, & Viswanathan, 2005; Paap & Greenberg, 2013). Although there are many possible reasons for this difference in outcome (Bak, 2016; Bialystok, 2016),

the inconsistent findings raise questions about the reliability of the effects and the nature of the mechanisms that underlie them. To understand the potential effects of bilingualism, therefore, an approach is needed that goes beyond these standard studies and investigates the mechanism by which the effects occur. This study examines the hypothesis that the executive function differences found for monolinguals and bilinguals can be traced to differences in attentional control and that these differences can be detected as early as infancy.

The most common explanation for bilingual advantages in executive function is attributed to the established finding that both languages in the bilingual mind are jointly activated so some mechanism is needed to avoid interference from the unwanted language (review in Kroll, Dussias, Bogulski, & Valdes Kroff, 2012). Therefore, early explanations for the bilingual effects on executive function

were based on the notion of inhibition (Green, 1998); specifically, bilinguals inhibit the unwanted language, providing training in inhibition that can transfer to other domains. However, the inhibition account was problematic: the unwanted language continued to influence processing (e.g., Wu & Thierry, 2010) and only some forms of non-verbal inhibition were affected by bilingualism (Luk, Anderson, Craik, Grady, & Bialystok, 2010; Martin-Rhee & Bialystok, 2008). For these reasons, the formulation proposed by Costa (2005) was appealing: the mechanism for dealing with jointly activated languages was not inhibition but rather selection, a concept that is subtly but importantly different. Selection is integral to notions of attention, and as argued by Bialystok (2015), recasting the problem in terms of attention and selection has the potential to integrate empirical evidence from executive function tasks with broad notions of attention in a more complete way. However, the relation between general attention and language selection is difficult to disentangle.

One approach to this issue comes from research examining the effects of bilingual environments on infants' attentional development in the first year of life. In the early months, infants attend primarily to the eyes of an adult speaking to them, possibly because of the importance for social interaction (Haith, Bergman, & Moore, 1977). Toward the latter half of the first year, infants begin to attend more to the mouth than to the eyes (Tenenbaum, Shah, Sobel, Malle, & Morgan, 2013). This shift gives infants access to audiovisual speech cues pertaining to the language being spoken and facilitates language acquisition (Lewkowicz & Hansen-Tift, 2012). A recent study by Tsang, Atagi, and Johnson (2018) confirmed a relation between attention to talking mouths and increasing verbal skills for both monolingual and bilingual infants between 6 and 12 months old, but the shift of attention from the eyes to the mouth was found earlier for infants exposed to bilingual environments than for those in monolingual environments (Ayneto & Sebastián-Gallés, 2017).

Compelling evidence for infants' attention to language comes from studies showing that newborn infants can recognize and discriminate languages to which they were exposed during pregnancy. Byers-Heinlein, Burns, and Werker (2010) compared performance of newborn infants whose mothers had exposed them to a monolingual (English) or bilingual (English and Tagalog) environment during pregnancy on an auditory familiarity task. Infants heard alternating 1-min samples of English and Tagalog while they sucked a pacifier that recorded sucking frequency as an index of familiarity and interest. Infants exposed to monolingual environments during pregnancy showed a preference for the English samples but infants exposed to bilingual environments showed equivalent interest in both, indicating recognition of the languages heard prenatally. Moreover, the bilingually exposed infants could also discriminate between the two languages as indicated by their ability to dishabituate after a language switch.

Using older infants, Pons, Bosch, and Lewkowicz (2015) compared infants raised in monolingual or bilingual environments for their ability to exploit audiovisual speech cues during social interactions. Eye movements of 4-, 8-, and 12-month-old infants were recorded while they viewed videos of a speaker reciting a monolog

RESEARCH HIGHLIGHTS

- Language environment does not influence infants' propensity to form or exhibit expectations for non-verbal stimuli.
- However, bilingual infants update expectations for non-verbal stimuli more efficiently than monolingual infants.
- Bilingual environments influence the development of attentional control in infancy.
- Exposure to bilingual environments may partly account for cognitive differences observed across the lifespan between monolinguals and bilinguals.

in a language that was familiar (Catalan or Spanish) or unfamiliar (English). Infants raised in monolingual environments looked more at the speaker's eyes at 4 months and at the mouth at 8 months regardless of the language, but at 12 months they preferred the mouth for an unfamiliar language, with no preference for a familiar language. For bilinguals, there was no preference for mouth or eyes in either language at 4 months, but at 8 and 12 months, they preferred looking at the mouth for both languages. Thus, bilingual infants attended the salient audiovisual speech cues in social interactions at a younger age and persisted in that strategy longer than did infants in monolingual environments.

Since the bilingual infants displayed no looking preferences for familiar or unfamiliar languages, it is possible that they could not distinguish between them. However, a series of studies clearly demonstrates that not only do bilingual infants distinguish between languages but they also do this more effectively than comparable monolingual infants. In the first study, Weikum et al. (2007) tested 4-, 6-, and 8-month old infants who were being raised with only English or both English and French in the home. The infants were shown silent videos of a talking face reading sentences in either English or French, and after the infant habituated, the language switched to the other one, although only visual cues were available. At 4 and 6 months, all infants became interested again after the language switch, but at 8 months, only bilingual infants noticed that the language had changed. To confirm that the relevant factor was exposure to a bilingual environment and not familiarity with the specific languages, the study was repeated in Barcelona with monolingual and bilingual infants who had never been exposed to English or French (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). As in the previous study, 8-month-old infants who were Spanish-Catalan bilinguals noticed the switch between English and French but monolingual infants did not.

Selective attention may also be relevant for infants' ability to detect differences in linguistic structure. Singh, Fu, Tay, and Golinkoff (2017) investigated the ability of infants to learn words that differed by a vowel contrast (e.g., "bat" and "bet"). Eighteen-month-old infants

who were exposed to either monolingual (English or Mandarin) or bilingual (English and Mandarin) environments completed a word-learning habituation task. During the habituation phase, infants saw one moving stimulus (Object A) paired with an auditory label (Word A) and a different stimulus (Object B) paired with another label (Word B). In the test phase, infants saw the same (Object A, Word A) or switched pairs (Object A, Word B). All the infants looked at the habituation trials and the test trial with the preserved pairs for similar durations, but the bilingual group looked longer at the switched pairs, indicating that they detected the mismatch.

In a similar study, Kovács and Mehler (2009a) compared monolingual and bilingual 12-month-olds for their ability to learn strings of meaningless syllables that differed in their structure. Both groups of infants could learn the first sequence (e.g., AAB) but only bilingual infants could also learn the second (e.g., ABA). This flexibility in learning is likely grounded in their ability to detect and attend to the relevant features of the stimuli.

The studies reviewed to this point have focused on infants' attention to language, but the effects of bilingualism in adulthood have been found primarily in non-verbal domains. Therefore, if these differential developments in attention in infancy are to be related to the lifelong effects found for bilingualism, then they must also be demonstrated for attention to non-verbal stimuli. Studies with young children have demonstrated that bilingual children use different attention networks when performing executive function tasks than do monolingual children (Arredondo, Hu, Satterfield, & Kovelman, 2017; Barac, Moreno, & Bialystok, 2016).

The only study to date that has addressed this question in infants was conducted by Kovács and Mehler (2009b). Seven-month-old infants raised in monolingual or bilingual environments completed a cued attention task while their eye movements were recorded. A cue was presented at the center of a screen and then a target stimulus appeared either to the left or to the right of it. In the pre-switch block, the target stimulus always appeared on the same side and shifted to the opposite side in the post-switch block. All infants correctly anticipated the appearance of the target stimulus in the pre-switch block, but only the bilingual infants correctly anticipated the target's location after the switch. Thus, the bilingual infants were more successful in controlling attention after the location had changed.

Although compelling, several design issues make the results difficult to interpret. First, the position of the target was always the same in the pre-switch condition, and then switched to a constant post-switch position, conflating position and switch condition. Therefore, responses in the post-switch condition may indicate a familiarity preference for monolinguals but a novelty preference for bilinguals. Since familiarity preference precedes novelty preference (Cashon & Cohen, 2000; Cohen, 2004; Hunter, Ames, & Koopman, 1983; Schilling, 2000), bilingualism may simply accelerate that shift. Second, the cue feature that predicted the target location was abstract structure of an auditory or visual triad that took the form AAB or ABB. This is challenging because the relevant information was not perceptual but relational, so it is unclear what information infants were using when they made correct

anticipatory eye movements. Third, the task only included 18 trials, 9 in each switch condition. Since infants elicit few anticipatory eye movements (Adler & Haith, 2003; Adler, Haith, Arehart, & Lanthier, 2008; Haith, Hazan, & Goodman, 1988) because the visual attention system is still developing (Johnson, 1990), anticipatory eye movements may be a weak assessment of group differences across trials. It may be more appropriate, therefore, to assess group performances by comparing the mean percent of correct anticipations in the pre- and post-switch conditions. Kovács and Mehler (2009b) reported the proportion of infants that correctly anticipated the target's location on each trial but these proportions are very sensitive to the performance of each infant—one additional infant correctly anticipating the target's location will increase the proportion by 5%—and do not provide a measure of variability.

For these reasons, a study that addresses these points is needed to determine whether infants raised in bilingual environments are more efficient at allocating attention to non-verbal stimuli than are those raised in monolingual environments. The purpose of the present study is to investigate the attention ability of infants raised in monolingual or bilingual environments using the Visual Expectation Cueing Paradigm (VExCP). In this paradigm, infants must discriminate between the perceptual parameters of two centrally presented cues used to anticipate the spatial location of a target stimulus (Baker, Tse, Gerhardstein, & Adler, 2008). That infants are required to use prior information encoded in an expectation representation to voluntarily guide appropriate behavior in anticipation of an event is necessarily served by the allocation of top-down selective attention. Since attentional responding in the present study was in the overt form of eye movements, and it is well accepted that a tight linkage exists between attentional allocation and the initiation or orienting of eye movements (e.g., Adler, Bala, & Krauzlis, 2002; Kowler, Anderson, Doshier, & Blaser, 1995; Van der Stigchel & Theeuwes, 2007), such that the eyes cannot go where attention is not, any facilitation of attentional mechanisms, therefore, as might occur due to language environment, will be manifested in subsequent eye movements. A number of models of visual attention development have postulated that the neural and attentional mechanisms necessary for reactive, bottom-up attentional selection are functional in the very first few months of life (Atkinson, 2000; Braddick & Atkinson, 2011; Johnson, 2002). These same models further postulate that the mechanisms necessary for top-down guidance of attentional allocation do not begin to show functionality until after 3 months of age, and become more functionally mature by 6 months of age (Amso & Scerif, 2015; Atkinson, 2000; Johnson, 2002; Richards, 2001). Because eye movements are guided by cognitive expectations for which stimulus will appear where and when (Adler & Haith, 2003; Adler et al., 2008; Baker et al., 2008; Haith et al., 1988), this current task primarily activates top-down attentional mechanisms that are functional in the infants participating in this study. To this end, any differences in the 6-month-olds' eye movements, either anticipatory or reactive, as function of their language environment would indicate differences in the developmental path of their attentional mechanisms.

The perceptual parameters used in the present study were color and shape, as infants have been observed to encode this information when predicting a target's spatial location (Adler & Haith, 2003; Hochmann, Carey, & Mehler, 2018). Evidence for better selective attention in bilingual infants will, consequently, help to isolate attention as a relevant process in explaining cognitive differences between monolinguals and bilinguals later in life. It will also reduce the emphasis on language selection and switching as the underlying mechanism for bilingual effects on executive function.

2 | STUDY 1

The first study assessed whether exposure to monolingual or bilingual environments influences infants' ability to form visual expectations and initiate eye movements toward targets on a screen. Forming visual expectations requires the ability to detect and encode regularities in the visual environment. Previous research has indicated that infants raised in both monolingual and bilingual environments performed similarly on tasks that measure cued recall or working memory (Brito, Grenell, & Barr, 2014; Brito, Sebastián-Gallés, & Barr, 2015), so the hypothesis was that environment would not influence infants' ability to form expectations of cues predicting targets.

3 | METHOD

3.1 | Participants

Six-month-old infants raised in monolingual ($n = 10$) or bilingual ($n = 10$) environments, recruited from a mailing list supplied by a Toronto-area marketing company (Z Retail Marketing Company

Inc., Toronto, Canada), participated in the study. The home environment was determined by parents' self-report on the Language Social Background Questionnaire (LSBQ, adapted from Anderson Mak, Chahi, & Bialystok, 2018). The 20 infants (13 males, 7 females) ranged in age from 169 to 200 days ($M = 180.7$ days, $SD = 9.8$) and predominately had a middle social economic status (SES). The infants were of Caucasian ($n = 10$), Asian ($n = 4$), African ($n = 3$), Hispanic ($n = 1$), and Other ($n = 2$) ethnic backgrounds. The languages spoken in the bilingual homes included Cantonese ($n = 1$), Czech ($n = 1$), Gurati ($n = 1$), Italian ($n = 1$), Korean ($n = 1$), Persian ($n = 1$), Portuguese ($n = 1$), Russian ($n = 1$), Spanish ($n = 1$), and Yoruba ($n = 1$). In addition to English, parents reported as intentionally exposing their infant to a second language daily for about 60.8% ($SD = 20.9$) of the time. An additional 12 infants participated in the study but were excluded due to crying or general fussiness ($n = 6$), inattentiveness (i.e., provided data on less than 60% of the trials; $n = 3$), or experimental error (e.g., eye-tracker failed to detect eye movements; $n = 3$). All infants were born at full-term, in good health, and with no apparent visual, neurological, or other abnormalities as documented by parental recording. Informed consent was given by the parent of each infant.

3.2 | Stimuli and apparatus

The stimuli were computer-generated images approximately 4.5° degrees in diameter (see Figure 1). The cue stimuli included a pink and gray checkerboard and a blue and yellow bullseye, and the target stimulus was a green square with a smiling red star inside.

The infants were laid supine in a specialized crib and viewed the stimuli on a 19-inch LCD color monitor with 1,024 × 768 pixel resolution that was mounted 48 centimeters overhead. There

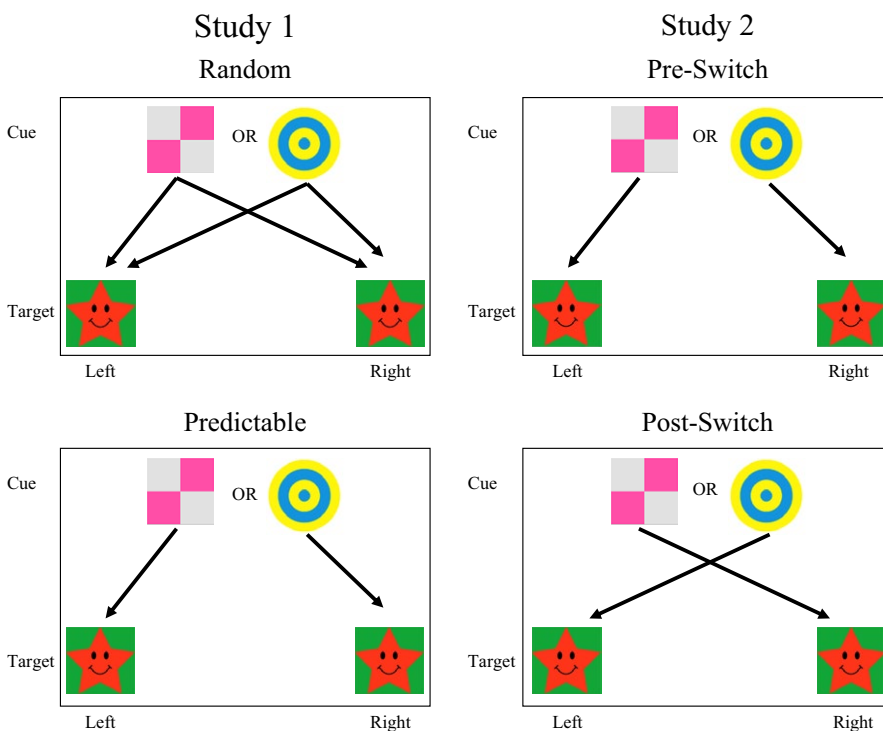


FIGURE 1 Schematic of stimuli and conditions in Studies 1 and 2. In Study 1, predictable cue–target location relations did not emerge until after the 30th trial was viewed. In Study 2, however, there were predictable cue–target location relations during both the pre-switch and post-switch, but the relations in the post-switch were contradictory to those in the pre-switch

was a 30 × 30 cm infrared-reflecting, visible-transmitting mirror between the infant and monitor. A remote, pan-tilt infrared eye-tracking camera (Model 504, Applied Science Laboratories [www.a-s-l.com], Bedford, MA) emitted infrared light that was reflected off the mirror and into the infant's eye. The reflection of the infrared light coming back from the infant and off the mirror was recorded by the camera at a temporal resolution of 60 Hz. To minimize outside light entry into the crib, black felt curtains were drawn over and around the crib.

Infrared light emitted from the diodes on the camera reflected off the mirror into the infant's eye, and then reflected back from the infant's retina through the pupil, producing a backlit white pupil. In addition, the infrared light produced a point of reflection on the cornea of the infant's eye. Using proprietary software (Applied Sciences Laboratories), the eye fixation position was calculated as the relation between the centroid of the backlit pupil and the corneal reflection. The eye-tracker was calibrated by having each infant view a continuous loop of shapes and colors at two known locations on the screen. All future recorded eye-tracker fixation values were filtered through the calibration file to produce measures of eye position data.

Two Dell computers were used. The first generated and presented the stimuli using the program Direct RT (Empirisoft Inc., New York; www.empirisoft.com/DirectRT.aspx). These stimuli were relayed to the LCD monitor that was above the crib, allowing the experimenter to see what the infant was viewing. The second computer was used to control the eye-tracker and record the data collected from it. The stimulus-generating computer sent a unique, time-stamped numerical code, indicating the onset and type of trial, through a parallel port to the data-collecting computer. The synchronization of the unique code with the eye movement data in the data file allowed coordination of the eye movement sequences to specific stimuli and their onsets.

3.3 | Procedure

Each infant was exposed to 60 experimental trials divided into two blocks. Each trial started with one of the cues displayed at the center of a grayscale screen for 2,000 milliseconds. After cue offset, an interstimulus interval (ISI) of 750 milliseconds followed during which the screen was blank. After the ISI, the target stimulus was presented on the left or right side of the screen with a visual angle of 5.5° from the center. The target remained on the screen for 1,500 milliseconds. At target offset, the screen was blank for 500 milliseconds, and then one of the two cues appeared at the center of the screen signaling the onset of the next trial. The order that the cues appeared was randomized; but each cue was displayed for 30 trials.

For the first 30 trials, the random block, there was no relation between the cues and the position of the target. Trial 31 began the predictable block in which the cues reliably indicated the location at which the target would appear (see Figure 1). The cue–location relation was counterbalanced across participants. The random block served as a baseline measurement of chance eye movement performance when there were no predictable cue–location relations

upon which to form expectations. The predictable block, in contrast, served as baseline for infants' eye movements when the cue was reliable and could be used to form expectations.

3.4 | Data reduction and analysis

The raw digital data recorded by the eye-tracker were imported into a MATLAB toolbox called ILAB (Gitelman, 2002) for analysis. ILAB separated individual eye movements into their horizontal and vertical components while displaying the components on a trial-by-trial basis. ILAB also displayed the scan path of the eye, which allowed eye movements to be analyzed based on their timing, direction, and distance relative to the stimuli on screen.

For an eye movement to be included in the final data sample, it had to meet several criteria. First, like previous infant expectation studies (e.g., Adler & Haith, 2003; Haith et al., 1988; Haith & McCarty, 1990), the first 10 trials of the study were excluded from the final analysis to equate infants on their level of engagement with the task. Similarly, the final 10 trials were excluded because infants showed signs of fatigue at different points and were unable to complete the task. Deleting the first and last 10 trials led to an equal number of pre- and post-switch trials in which infants were actively engaged. Second, because the study was concerned with the formation of expectations, infants had to fixate on the cue preceding the target for the trial to be included. Third, eye movements were considered anticipatory if they occurred between 133 milliseconds after cue offset and 133 milliseconds after target onset. This latency value was chosen as the anticipation cut-off because it has been previously determined that 6-month-old infants cannot make eye movements in reaction to the onset of a stimulus faster than 133 milliseconds (Canfield, Smith, Brezsnayak, & Snow, 1997). Eye movements occurring between 133 milliseconds after target onset and 133 milliseconds after target offset were considered to be reactive. Fourth, infant's data were included only for those infants who had looked at the stimuli on a minimum of 60% of the trials in both the first and second half of the study to ensure adequate attention was present throughout the task. Finally, the eye movement to the target had to trace a path that was more than 50% of the distance between the cue and the target. The 50% criterion has been used in previous studies of infants' eye movements (e.g., Adler & Haith, 2003; Adler & Orprecio, 2006) and is typically taken as an indication that the eye movement was intentional and not random.

Eye movement data were analyzed in terms of three dependent measures. First, a total anticipation measure was calculated by taking the percentage of all valid eye movements that were made to the targets which were anticipations (correct and incorrect). Second, a correct anticipation measure was calculated in terms of the percent of all anticipations that correctly localized target locations. Finally, the median reactive latencies of all eye movements toward the targets that were not anticipatory were calculated because reactive eye movements can also be facilitated by underlying expectations (Haith et al., 1988; Haith & McCarty, 1990; Haith, Wentworth, & Canfield, 1993).

4 | RESULTS AND DISCUSSION

4.1 | Anticipations

The first step was to ensure that possible differences between groups in anticipatory eye movements were not due to the total number of anticipations made. The percent of total anticipations is shown in Table 1. A 2×2 mixed-design analysis of variance (ANOVA) with Group (monolingual, bilingual) as a between-participant factor and Condition (random, predictable) as a within-participant factor indicated no significant main effects or interactions, all $F_s < 1$. Therefore, the total number of anticipations did not differ by language environment or the presence of predictable cue–location relations.

To determine if exposure to monolingual or bilingual environments influenced infants' ability to successfully form expectations, the percentage of anticipations that correctly predicted the target's location was assessed. Since there were no predictable cue–location relations in the random condition, correct anticipations should occur on about 50% of the trials for which there was an anticipatory eye movement (chance performance), but the percent of correct anticipations in the predictable condition should be greater than 50%.

A 2×2 mixed-design ANOVA was performed on the percent of correct anticipations with Group (monolingual, bilingual) as a between-participant factor and Condition (random, predictable) as a within-participant factor. There was a significant main effect of Condition, $F(1,18) = 4.62$, $p < 0.05$, $d = 0.78$, indicating more correct anticipations in the predictable condition ($M = 75.00\%$, $SE = 5.43$) than in random condition ($M = 51.88\%$, $SE = 9.03$), supporting the interpretation that infants could discriminate the cues and form expectations. There was no main effect of Group or a Group by Condition interaction, both $F_s < 1$. These data are shown in Figure 2 collapsed across group.

The final analysis evaluated whether infants made correct anticipations at a rate greater than chance. One-tailed, one-sample t tests using the Benjamini–Hochberg procedure with a false discovery rate of 0.05 indicated that the monolingual group made correct anticipations at a rate greater than chance in the predictable condition, $t(6) = 3.16$, $p < 0.05$, $d = 1.19$, but not in the random condition, $t(6) = 0.57$, ns . Similarly, the bilingual group made correct anticipations at a rate greater than chance in the predictable condition, $t(8) = 3.16$, $p < 0.05$, $d = 1.05$, but not in the random condition, $t(8) = 0.35$, ns . Therefore, infants from both environments were

equally successful at forming expectations and making correct anticipations when predictable cue–location relations were present (see Figure 2).

4.2 | Reactive latencies

A 2×2 mixed-design ANOVA was performed on median reactive latencies with Group (monolingual, bilingual) as a between-participant factor and Condition (random, predictable) as a within-participant factor. There was a significant main effect of Condition, $F(1,18) = 4.67$, $p < 0.05$, $d = 0.49$, indicating faster reactive eye movements in the predictable ($M = 365$ msec, $SE = 26$) than random condition ($M = 420$ msec, $SE = 24$). Thus, infants experienced facilitated reactive eye latencies toward the target stimuli due to the emergence of predictable cue–target location relations that enabled them to form expectations of the target's location. There was no main effect of Group or interaction effect, $F_s < 1$. These data are shown in Figure 3 collapsed across group. Therefore, there is no evidence for differences in the formation of visual expectations that can be attributed to language environment.

4.3 | Study 2

The results from Study 1 suggest that exposure to monolingual or bilingual environments does not influence infants' ability to form expectations and initiate eye movements toward targets. Therefore, potential differences in the ability of infants from these two language environments to switch attention cannot be attributed to underlying differences in detecting valid cues or forming expectations. However, infants raised in bilingual environments have experience in discriminating between and allocating attention to two distinct languages, something they do without confusing the languages (e.g., study by Weikum et al., 2007, described above). Therefore, the unique ability of infants in bilingual environments may be to attend better to environmental distinctions and to use those expectations in a controlled way, updating and shifting between them when necessary. Such ability would indicate attentional control, a precursor to executive function.

Study 2 used a variant of the VExCP that challenges infants to be flexible with their attention as they must modify existing expectations when the cue–target location relation changes in order to correctly predict the location of subsequent targets. If exposure to bilingual environments influences infants' ability to efficiently allocate their attention, then infants in bilingual environments will show more flexibility than infants in monolingual environments for updating existing expectations when the cue–position relation changes.

TABLE 1 Percent of total anticipations (standard error) made during studies 1 and 2

	Monolingual	Bilingual
Study 1		
Random	11.62 (3.79)	14.71 (3.00)
Predictable	14.26 (4.48)	15.50 (2.30)
Study 2		
Pre-switch	13.28 (2.15)	14.02 (2.28)
Post-switch	16.16 (3.22)	16.78 (2.71)

5 | METHOD

5.1 | Participants

Six-month-old infants raised in monolingual ($n = 20$) or bilingual ($n = 20$) environments, recruited from a mailing list supplied by a

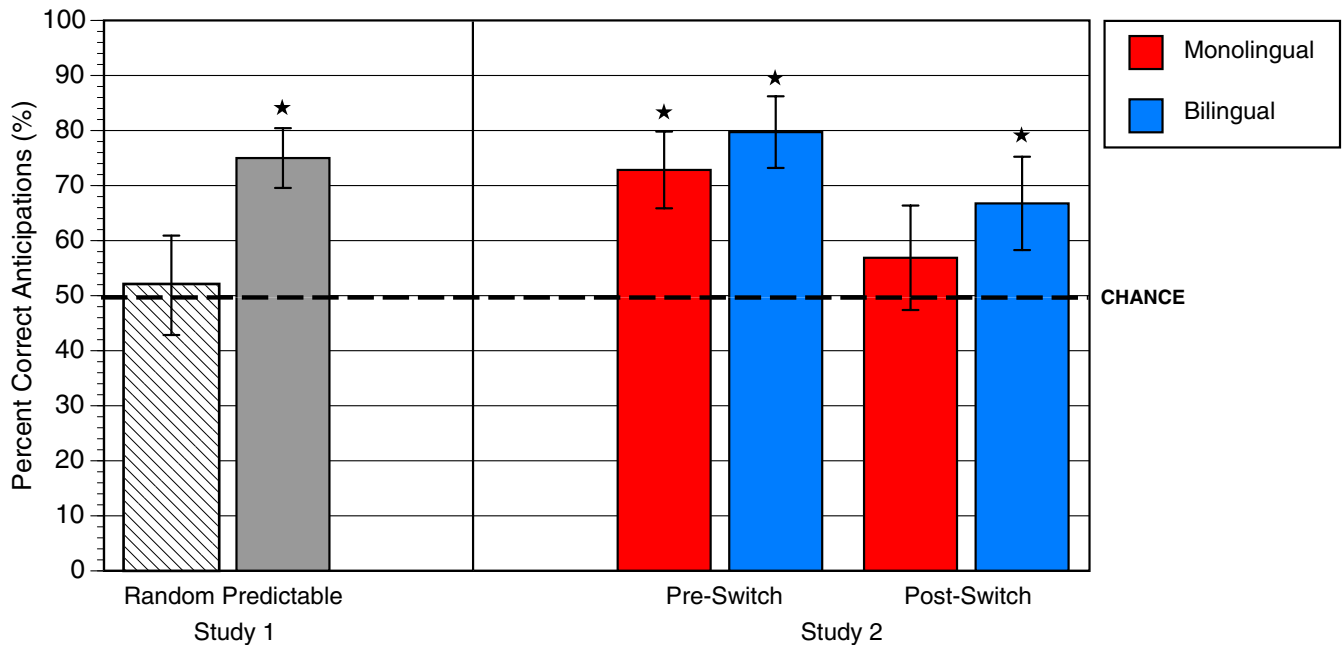


FIGURE 2 Mean percent of correct anticipations to the targets in Studies 1 and 2 by language group. The dashed line represents performance at chance (50%). Asterisks indicate performance that was significantly greater than chance performance. Error bars represent ± 1 standard error of the mean

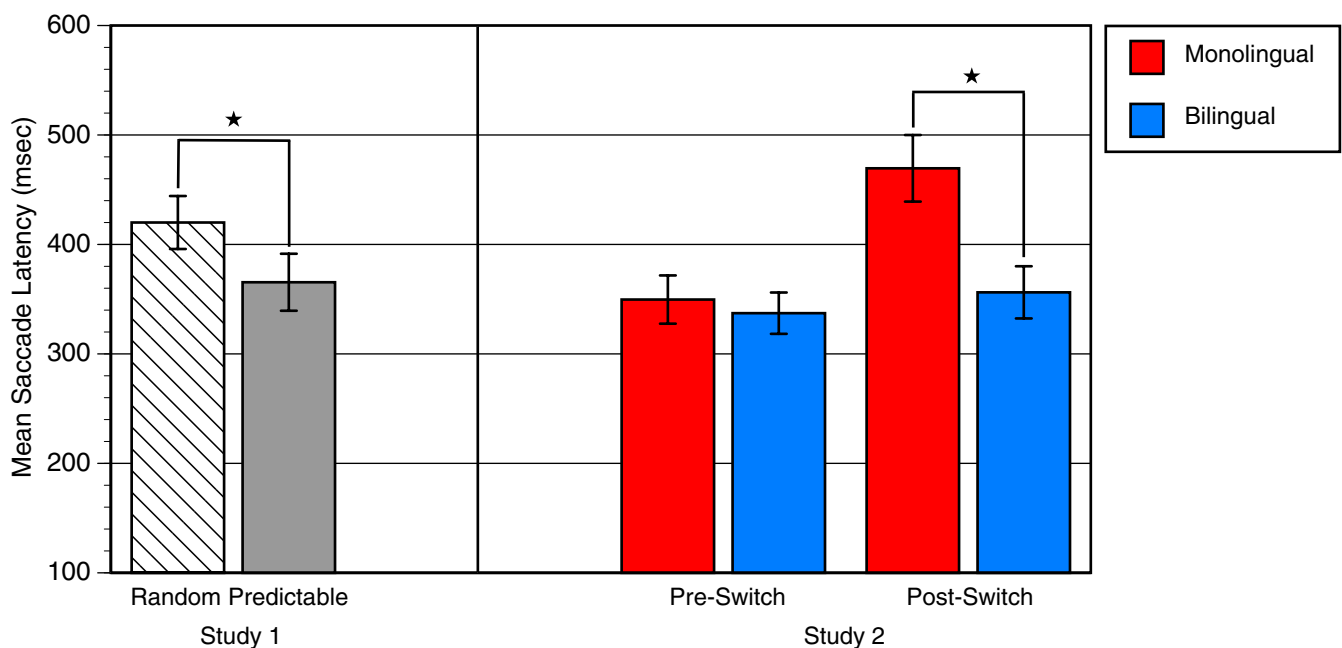


FIGURE 3 Mean reactive latencies to the targets in Studies 1 and 2 by language group. Asterisks indicate performances that were statistically distinct from one another. Error bars represent ± 1 standard error of the mean

Toronto-area marketing company (Z Retail Marketing Company Inc., Toronto, Canada), participated in the study. The home environment was determined by parents' self-report on the LSBQ (as used in Study 1). The 40 infants (19 males, 21 females) ranged in age from 167 to 210 days ($M = 184.2$ days, $SD = 11.3$) and predominantly had a middle social economic status (SES). The infants were of Caucasian ($n = 22$), Asian ($n = 2$), African ($n = 3$), Hispanic

($n = 3$), and Other ($n = 10$) ethnic backgrounds. The languages spoken in the bilingual homes included Arabic ($n = 2$), Cantonese ($n = 2$), French ($n = 2$), Italian ($n = 2$), Mandarin ($n = 1$), Portuguese ($n = 3$), Russian ($n = 2$), Spanish ($n = 3$), Tagalog ($n = 1$), Twi ($n = 1$), and Urdu ($n = 1$). In addition to English, parents reported as intentionally exposing their infant to a second language daily for about 45.8% ($SD = 23.7$) of the time. An additional 38 infants

participated but were excluded due to crying or general fussiness ($n = 20$), inattentiveness (i.e., provided data on less than 60% of the trials; $n = 10$), or experimental error (e.g., eye-tracker failed to detect eye movements; $n = 8$). All infants were born at full-term, in good health, and with no apparent visual, neurological, or other abnormalities as documented by parental recording. Informed consent was given by the parent of each infant.

5.2 | Stimuli and apparatus

The stimuli and apparatus used for Study 2 were identical to those used in Study 1.

5.2.1 | Procedure

The procedures were the same as those in Study 1 but the structure of the blocks was different. The first 30 trials, pre-switch, contained predictable cue–position relations but the associations switched in the second block of 30 trials, post-switch, so each cue predicted the opposite location (see Figure 1). The cue–location relation was counterbalanced across participants. The pre-switch condition served as a measurement of eye movement performance to predictable relations and was comparable to the predictable block in Study 1. The post-switch condition indicated infants' ability to update those expectations as new predictable cue–location relations emerged.

5.2.2 | Data reduction and analysis

The data reduction and analyses in Study 2 were identical to those used in Study 1.

6 | RESULTS AND DISCUSSION

6.1 | Anticipations

The percent of total anticipations is shown in Table 1. A 2×2 mixed-design ANOVA for Group and Switch (pre-switch, post-switch) indicated no significant effects or interactions, all $F_s < 1.39$. Therefore, differences in correct anticipations cannot be attributed to a difference in total anticipations.

The percentages of correct anticipations by group are shown in Figure 2. A 2×2 mixed-design ANOVA indicated no effect of Group, $F(1,38) = 1.06$, *ns*, Switch, $F(1,38) = 3.33$, *ns*, or their interaction, $F < 1$. Therefore, the overall rate of correct anticipations did not differ by language environment or switch condition.

Finally, to establish whether anticipations were reflecting random behavior, correct anticipations were examined as a function of chance performance (50%). Planned comparison one-tailed, one-sample *t* tests using the Benjamini–Hochberg procedure with a false discovery rate of 0.05 indicated that the monolingual group made correct anticipations at a rate greater than chance in pre-switch ($M = 72.84\%$, $SE = 6.97$), $t(16) = 3.28$, $p < 0.01$, $d = 0.80$, but not in

post-switch ($M = 56.88\%$, $SE = 9.49$), $t(15) = 0.72$, *ns*. In contrast, the bilingual group made correct anticipations more frequently than by chance in both pre-switch ($M = 79.71\%$, $SE = 6.51$), $t(16) = 4.56$, $p < 0.001$, $d = 1.11$, and post-switch blocks ($M = 66.76\%$, $SE = 8.48$), $t(16) = 1.98$, $p < 0.05$, $d = 0.48$. Thus, only infants raised in bilingual environments successfully updated their expectations when new and contradictory cue–location relations emerged in the post-switch condition (see Figure 3).

6.2 | Reactive latencies

Median latencies of reactive eye movements are presented in Figure 3. A 2×2 mixed-design ANOVA revealed significant main effects of Group (monolingual, bilingual), $F(1,38) = 4.58$, $p < 0.05$, $d = 0.55$, and Switch (pre-switch, post-switch), $F(1,38) = 15.86$, $p < 0.001$, $d = 0.61$, and a significant interaction between them, $F(1,38) = 8.36$, $p < 0.01$, $d = 0.44$.

To explain the interaction, planned comparisons were conducted for each condition. In the pre-switch condition, monolingual ($M = 350$ msec, $SE = 22$) and bilingual ($M = 337$ msec, $SE = 19$) infants produced similar reactive latencies, $F(1,38) = 0.18$, *ns*, but in the post-switch condition, bilinguals ($M = 356$ msec, $SE = 24$) responded more rapidly than monolinguals ($M = 470$ msec, $SE = 30$), $F(1,38) = 7.40$, $p < 0.01$, $d = 0.93$. Put another way, the monolingual group exhibited slower reactive latencies in post-switch than pre-switch, $F(1,38) = 10.19$, $p < 0.01$, $d = 1.01$, but the bilingual group showed similar reactive latencies in both conditions, $F(1,38) = 0.39$, *ns*. Together, these findings indicate that infants exposed to bilingual environments were more efficient than infants exposed to monolingual environments at updating expectations.

7 | GENERAL DISCUSSION

The purpose of this study was to investigate whether the language environment affected infants' performance on a task that probed their ability to control and allocate attention. The larger goal was to determine whether differences in attentional control could be detected in infancy on a non-verbal conflict task, thereby providing a possible basis for cognitive differences that appear later in executive function. Such evidence would restrict the importance of language selection and switching as the primary mechanism for bilingual effects on executive functioning. In the VExCP, infants needed to detect predictable associations between cues and the location of a target so they could form an expectation for the target's future location. This step was determined by measuring the percentage of correct anticipatory eye movements to the target. All infants were able to do this. The next step, however, was to reverse that expectation so the same cue predicted the opposite location, requiring attention to the cue and the ability to associate that cue with a new location. Only bilingual infants could do this.

Study 1 assessed possible differences in infants' ability to form expectations and initiate eye movements when predictable

cue–target location relations emerged halfway through the VExCP study. Here, the language environment had no effect on infants' ability to perform the task whether or not there were predictable relations with the cue. An overall facilitation of reactive eye movement latencies was also observed, as the onset of reactive eye movements toward the target was shorter when predictable cue–target location relations were present than when they were random. These findings from Study 1 indicate that 6-month-old infants can form expectations and use those representations to direct eye movement to find a target.

Study 2 assessed differences in infants' ability to control attention when existing expectations needed to be modified. After establishing an association between a stimulus cue and a target location, a switch occurred so that each cue predicted the target in the opposite location. Therefore, to correctly anticipate the target's location and express facilitated latencies of reactive eye movements toward it during the post-switch, infants had to update their existing expectations of the cue–target relations.

Anticipatory eye movements revealed that all infants were able to correctly predict the target's location in the pre-switch, but only infants exposed to bilingual environments were able to reliably anticipate the target's location in the post-switch. Similarly, all infants expressed similar reactive eye latencies toward the target in the pre-switch, but infants exposed to bilingual environments expressed faster reactive latencies toward the target in the post-switch than infants exposed to monolingual environments. These findings point to an effect of bilingual environments on infants' ability to control and allocate attention when updating expectations in their visual environment.

Comparing group performances in Study 2, infants exposed to bilingual environments were more efficient than infants exposed to monolingual environments at updating their expectations in the post-switch. However, all the infants were attempting to adjust to the post-switch relations, as none of the results indicated below chance performance, the result that would be expected if infants persisted in using the pre-switch associations. Furthermore, the difference in performance between groups cannot be attributed to general learning differences, as the findings from Study 1 demonstrated that all the infants could successfully form expectations during the latter half of a study using the VExCP. Therefore, all the infants were attempting to perform the task but infants raised in bilingual environments were further along in their progress. These findings are consistent with the interpretation that exposure to bilingual environments leads to more precocious development of attentional control than is found for those exposed to monolingual environments.

The present study provides evidence for bilingual environments influencing the development of attentional control in infancy as a means for infants to monitor their complex representations of language. The development of enhanced attentional control supports previous studies where bilingual children outperformed monolingual children on tasks that measured attentional mechanisms, such as inhibitory control (Barac, Bialystok, Castro, & Sanchez, 2014), but

suggests an origin for these effects in infants' early perceptual interactions with their environment (Bialystok, 2015). For infants raised with two languages, that environment is more complex than that in a single-language home, and infants respond by quickly developing attention strategies to accommodate that complexity. In a recent study, Nacar Garcia, Guerrero-Mosquera, Colomer, and Sebastián-Gallés (2018) used EEG recordings to show that 4.5-month-old infants who were monolingual or bilingual used different attention strategies to discriminate between languages. Our claim is that these early differences in attention constitute an adaptation of attention that provides a foundation for developing executive function skills.

Although it is not necessary for bilingualism to begin at birth to observe the enhancements in executive function that have been reported across the lifespan, the early developments of attention in infancy provides a plausible basis for one factor in explaining how these differences may evolve, particularly in childhood. Individuals who become bilingual later in life may build on their experiences in different ways, including language switching, to achieve these effects. However, exposure to bilingual environments should be considered a significant factor in the early development of attention in infancy and a possible basis of lifelong cognitive benefit.

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