

ATTENTIONAL SWITCHING IN INFANTS EXPOSED TO BILINGUAL- VERSUS  
MONOLINGUAL ENVIRONMENT

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## Abstract

Acquiring two languages poses a challenge to bilingual individuals, but the process of switching attention between two languages may equip bilinguals with enhanced cognitive control abilities such as top-down attentional control. In the current study, 6- to 7-month-old monolingually- and bilingually-exposed infants were examined on a task that required the use of top-down attentional control. Using a task called the Visual Expectation Cueing Paradigm (VExCP), infants' anticipatory eye movements (EM) were measured to determine if they could override the previously learned cue-target side relation presented during pre-switch and learn the new cue-target side relation in post-switch. Although monolingually- and bilingually-exposed infants showed relatively equal number of correct anticipatory EM initially during post-switch, bilingually-exposed infants, towards the end of the task, outperformed monolingually-exposed infants in exhibiting correct anticipatory EM.

*Keywords:* infancy, attentional switching, visual expectations, bilingualism

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## **Attentional Switching in Infants Exposed to Bilingual- versus Monolingual Environments**

Our current understanding of attentional development during infancy is incomplete. Specifically, there is inadequate consideration of the experiences such as exposure to dual language environments that might modulate changes in attentional processing during the first year. Language is a particularly critical experience in the formative years during infancy and childhood, and the language environment to which we are exposed early in life can impact our cognitive development (Goldin-Meadow, Levine, Hedges, Huttenlocher, Raudenbush, & Small, 2014). The trajectory of attentional development, therefore, may be influenced by the nature of language exposure in early infancy.

A substantial body of research has revealed superior performance by bilingual children and adults on various cognitive tasks that engage attentional process (e.g., Bialystok, 1999; Bialystok, Craik, & Luk, 2008; Bialystok & Martin, 2004). However, attentional processes in early infancy have been less systematically investigated. Thus, we attempted to illuminate an attentional mechanism, particularly attentional switching in infants as function of mere *exposure* to a bilingual environment, to begin to decipher the role of early experience with dual-language environment on attentional processes during infancy.

### **Mechanisms involved in Attentional Switching**

Intelligent behavior requires selective attention to task-relevant information, inhibition of interference from irrelevant information, and attentional switching between sources of information as task-relevance changes (Hanania & Smith, 2010).

*Attentional switching* is the ability to shift attention between one task and another (Jersild, 1927). In order to do so, a combination of multiple components, rather than a single operation, is required to disengage current attention, inhibit the attention from returning to current stimulus, and selectively attending to the different stimulus (Posner, 1980). Thus, there are two main mechanisms involved in process of switching attention: selective attention and inhibition of return.

*Selective attention*, a fundamental mechanism involved in attentional switching, primes the attentional system to respond to certain types of input and ignore others. In other words, selective attention is the ability to maintain attention on one stimulus rather than another (Posner, 1980). Infants are selective in their attention from the first day of life. This phenomenon was observed in a study by Fantz (1961) in which newborn infants looked longer at some pictures or patterns than others. This visual behavior by newborn infants generated many other studies in this field, documenting that infants attend to various aspects of images, objects and events as they develop (Fantz & Fagan, 1975; Cohen, Deloache, & Strauss, 1979). For instance, during scanning and attending to human faces, 1-month-old infants tend to visually fixate their gaze at the perimeter of the face more than the internal features (Maurer & Salapatek, 1976). Similarly, during looking at objects, infants under 2 months tend to select the external contours of objects or patterns and ignore the internal details (Salapatek, 1975; Milewski, 1976). By 2 months of age, infants distribute their gaze, and presumably their selective attention, more broadly. This improvement in their attentional process has been associated with cortical maturation (Atkinson & Braddick, 2012).

Selective attention consists of both positive activation, that is, choosing the relevant target by visual search, and negative processes, including inhibition of return. *Inhibition of return*, an essential component involved in attentional switching, is the inhibition of attention to items or locations to which one has previously attended and searched (Posner & Cohen, 1984). Inhibition of return is mediated by the frontal cortex at all ages. Earlier research, however, fostered the belief that the frontal cortex was functionally silent until the end of the first year of life (Hood & Atkinson, 1993). This claim suggested that infants younger than one year were completely passive in the allocation of their attention and lacked the capacity to selectively attend and inhibit attention (Colombo, 2001). Passive attention in infants was supported by the phenomenon of *sticky fixation* whereby infants at 1.5 and 3 months of age failed to disengage their attention from a particularly salient target whereas 6-month old infants could disengage and direct their attention towards a new target (Hood & Atkinson, 1993).

Other studies, however, have demonstrated infants' capacity to exercise control over their allocation of attention suggesting that the frontal cortex functions in infants as young as 3-4 months (Johnson, 1995; Clohessy, Posner, Rothbart, & Vecera, 1991) and perhaps even in newborns (Valenza, Simon, & Umiltà, 1994). Therefore, the ability underlying inhibition of return that engages the frontal cortex must be present in infants very early.

There is a dispute, however, over the onset and developmental course of inhibition of return in infants; for example, Clohessy et al (1991) reported that inhibition of return was absent in 3- and 4-month-olds, but this ability has been

observed in 4-month-olds (Johnson & Tucker 1996, Richards 2001), 3-month-olds (Harman, Posner, Rothbart, Thomas- Thrapp, 1994; Richards 2000) and in newborns (Valenza et al 1994; Simion, Valenza, Umilta & Dalla-Barba, 1995). Nevertheless, results from studies on the development of inhibition of return in infancy indicate that this ability is clearly present by 6 months of age (e.g., Hood, 1993; Richards, 2000).

### **Attentional Switching in Infants**

As important as it is to be able to selectively attend to stimuli and inhibit attention to return to irrelevant stimuli, it is equally important to be able to switch from one event to another. *Attentional switching* is the ability to shift attention between one task and another (Jersild, 1927), and it is a crucial aspect of human development because it allows infants to learn and direct attention to relevant events through shifting or switching attention from one visual stimulus to another (Kulke, Atkinson & Braddick, 2015).

In terms of the time that it takes for an infant to switch attention inter-stimuli, infants at 1 month of age show a “glued” gaze to a particular contour for up to several minutes in length (Maurer & Lewis, 1991). From 2 to 3 months of age, there is a developmental transition in switching attention in infants. A study by Bronson (1991) showed that 2-week-olds looked back and forth between two patterns on less than 50% of the trials, whereas 12- week- olds readily shifted from one point to the other. Consistent with this result, Ruff (1975) reported a fourfold increase in looking back and forth between two patterns in the age range from 2 to 5 months. Also, a doubling of the rate of shifting was observed in infants from 4 to 7 months of age (Colombo, Mitchell & Horowitz, 1988). Generally, studies of infants’ capacity to shift attention suggest that

infants switch their visual attention once every 7 seconds at 2 months, once every 3 seconds around 4 months, and once every 1.7 seconds from 5 to 7 months (Ruff, 1975; Colombo et al, 1988).

In addition to development in the frequency of switching with age, infants show change in the quality or nature of shifting. For instance, typically developing infants in the first months of life can switch their gaze from a central target to a salient target appearing in the periphery in the absence of distractors in the visual field (Atkinson, Hood, Wattam-Bell, & Braddick, 1992), but by 3 months infants will use their visual periphery to discriminate between targets in the presence of distractors, moving their eyes to the preferred stimulus (Maurer & Lewis, 1991). Their eye movements, however, are still slower than adults' in initiation time (several seconds vs. 200 ms) (Aslin, 1987).

Similar to variability in the data on the onset of the ability to exhibit selective attention and inhibition of return in infants (e.g. Clohessy et al, 1991; Hood et al, 1993), there are various ages reported for initiation of the ability to have control over switching attention. Some researchers believe that infants in the first 2–4 months of life do not switch their gaze away from the central target in the presence of another peripheral stimulus (Atkinson, Hood, Braddick & Wattam-Bell, 1988; Johnson, Posner & Rothbart, 1991; Atkinson et al, 1992). In this situation, infants appear unable to disengage their attention from the central stimulus and switch to another stimulus, although some studies have reported that the failure to disengage and switch rarely occurs after age 2–3 months in typical development (Atkinson et al, 1988; Johnson et al, 1991).

Results from different studies, however, converge on the conclusion that infants have more control over the switching of attention by 4 months of age (e.g, Atkinson & Braddick, 2012; Johnson et al, 1991) and inter-stimulus switching becomes more common and faster than in younger infants (Colombo et al 1988; Ruff, 1975). For example, in paired-comparison tests, lack of inter-stimulus shifting is four times more likely to be observed in 3-month-olds (Frick et al 2000) than it is at 4 months (e.g. Colombo et al 1991). This considerable developmental improvement in attentional switching is taken as indirect evidence that may reflect cortical control emerging at around 4 months of age, allowing the infant to shift attention more flexibly at older ages (Braddick & Atkinson, 2011; Atkinson & Braddick, 2012).

In the first months of life, therefore, infants orient to novel and salient events, they maintain attention to those events, and gradually gain more control over their attention to switch more easily from one item of focus to another. By the age of 6 months, infants display the ability to integrate all mechanisms required for attentional switching. By virtue of having increased experience with events in the world, infants develop the ability to deploy their attentional switching capacity based on expectations rather than in response to immediate stimulation only (Neisser, 1979). Thus they exhibit the ability to anticipate events that as a cognitively driven process is indicative of initiation of top-down activation in infants' attentional switching.

### **Top-down Attentional processes and Anticipatory Eye Movement**

Attention is characterized as *top-down* (cognitively driven) or *bottom-up* (stimulus-driven) depending on the nature of the control processes involved. Bottom-up mechanisms are thought to operate rapidly and involuntarily in switching attention to

salient visual features (Connor, Egeth, & Yantis, 2004); for example, finding a red arrow among green arrows engages bottom-up attentional activation. In contrast, top-down mechanisms implement cognitive strategies and are involved in tasks that require the cognitive ability to make decisions, indicating goal-driven cognition (Park & Smith, 1989); for instance, finding arrows that are pointed to right direction among a set of arrows that are pointing to right and left directions engages top-down attentional processing.

Here we define top-down attentional mechanisms as being reflected in anticipatory eye movements which have to be emitted by using cognitive process because there is no proximal stimulus perceptually available to elicit that eye movement. Anticipatory eye movements require infants to apply a cognitive capacity not only for learning and remembering the sequence of events but also for forming expectations of forthcoming events that are not yet perceptually available. Thus, producing anticipatory eye movements requires the allocation of attention toward an expected event in a top-down manner as there is no stimulus available to drive bottom-up attention. Top-down visual attentional control in infants, therefore, could be examined through their anticipatory eye movements that are endogenously generated and intentionally directed toward an item or location of interest, indicating a top-down attentional process.

The initiation of the ability to form visual expectations or anticipations has been observed in a study by Canfield and Haith (1991), in which 2 and 3 month old infants were randomly assigned to one of the following conditions. In a simple alternating condition, called a 1-1 sequence, infants were presented with one image appearing on

the left and then with an image appearing on the right. Following the simple alternation, infants saw a 2-1 alternating condition in which the images appeared, for example, twice on the left then once on the right (or vice versa). In a 3-1 condition, the images appeared three times on the left and then once on the right (or vice versa). Finally, in an irregular condition, the images appeared on each side of the screen in an unpredictable sequence. The results from analyses of anticipatory fixations indicated that by 2 months of age infants could rapidly, within 2 minutes, form an expectation only for the reappearance of a simple alternate-side event or 1-1 sequence. By 3 months of age, infants rapidly formed expectations for 1-1 and 2-1 sequences but could not anticipate more complex sequences. Therefore, the ability to anticipate the locations of forthcoming simple sequence picture presentations is present at 2 months of age. As infants get older, between 3 to 4 months of age, show higher frequency of anticipatory eye movements (Canfield & Haith, 1991; Johnson et al., 1991).

Adler and Haith (2003) showed that infants as young as 3 and 4 month old form expectations, not only for the spatial location of visual events, but also for their content feature of events, defined as “invariant color combination”. In this study, 3 and 4-month-old infants were presented with images that flashed in a preset spatial pattern on a computer screen, e.g. left-right-left-right. Images with invariant colors always appeared with the same color combination (e.g., red/green) on one side of the screen while images with varied colors (4 different colors) appeared on the other side of the screen. After less than a minute of exposure to this sequence, infants began making anticipatory eye movements toward the location where the next picture would appear.

Results from infants' anticipatory eye movements indicated that infants formed a content expectation for the invariant color combination on the invariant side.

As infants become older, at around 4 months of age, they display the ability to anticipate peripheral events on the basis of a central cue (Johnson et al., 1991). In a study by Johnson and his colleagues (1991), infants of 2, 3, and 4 months of age were examined to find the age of onset and sequence of development of the ability to use a central stimulus to predict the spatial location of a target. During the experiment, one of the two cue stimuli appeared in the center of the screen in random sequence, followed by a peripheral target stimulus appearing on either left or right side of the screen. Whether the peripheral target stimulus appeared to the right or to the left of the cue stimulus was contingent on which of the two cue stimuli had been presented prior the target stimulus. Each of two cue stimuli, therefore, predicted the appearance of a target on a specific peripheral side of the screen. Results indicated that only 4-month-old infants were readily able to disengage from a central cue and to switch attention toward the peripheral target.

This impressive capacity of infants to anticipate the location of upcoming images that are not perceptually available may indicate the beginning of the ability to deploy top-down cognitive processes. There is ongoing debate, however, over the onset of full brain maturity to operate these higher cognitive tasks optimally. Current models of visual attention development postulate that neurological substrates known to underlie endogenous, top-down control of attentional allocation are not fully functional until at least 6 months of age (Atkinson, 1984, 2000; Braddick & Atkinson, 2011; Johnson,

1995, 2002). The age at which infants are fully able to exhibit cognitive advantages in top-down attentional processes remains uncertain.

One of the factors that has been reported to boost attentional switching, and possibly engage top-down attentional control in shifting attention, is bilingualism. To date, a substantial body of research has revealed superior performance by bilingual children and adults on various cognitive tasks that engage attentional mechanisms (e.g., Bialystok, 1999; Bialystok, Craik, & Luk, 2008; Bialystok & Martin, 2004, for review Bialystok, 2015). However, attentional processes, particularly attentional switching in early infancy has been less systematically investigated as a function of exposure to a bilingual environment.

## **BILINGUALISM**

### **Bilingual Effect on Attentional Process**

The language environment that children experience influences the quality of the cognitive systems they develop (Goldin-Meadow et al., 2014), so it should not be surprising that bilingualism is an important factor in developmental outcomes (Bialystok, 2015). Several researchers have proposed candidate mechanisms for the bilingual effect on attentional performance, the most common of which is the inhibition. This notion is based on the assumption that while bilingualism requires co-activation of both languages, only one language can be used at a given moment (Bialystok et al., 2004, 2008, Costa, Hernández, & Sebastián-Gallés, 2008). Consequently, during speech production, bilinguals have to consistently inhibit the intrusion of the non-target language (Green, 1998) which may eventually lead to

superior performance in attentional tasks that require inhibiting the attention to return to previously attended stimulus. However, bilinguals outperform monolinguals also on tasks for which no inhibition is required (e.g. Bialystok, 2010). Thus, no robust evidence endorses the specificity of bilingual effects on inhibition (Hilchey & Klein, 2011).

Instead of inhibition, some researchers have proposed that the source of the bilingual advantage is in monitoring (Hilchey & Klein, 2011; Costa, Hernandez, Costa-Faidella & Sebastian-Galles, 2009). In some sense, inhibition and attentional switching both are incorporated in monitoring process that involves switching across stimuli and inhibiting the irrelevant stimulus while attending to relevant event.

One task that integrates both inhibition and monitoring is the dimension change card sort task (Zelazo, Frye & Rapus, 1996). This task makes use of a set of cards containing two-dimensional stimuli (e.g., colored shapes). The cards need to be classified based on one feature (color), then reclassified based on the other feature (shape). Optimal performance requires participants to ignore the previous dimension (inhibition) and switch attention to the newly relevant dimension (monitoring). A number of studies (e.g. Bialystok, 1999; Okanda, Moriguchi & Itakura, 2010) have shown that bilingual children outperformed their monolingual peers on this task. The results may suggest the contribution of an integrated cognitive system, including switching attention, to bilingual advantages.

Switching attention can be considered as one of the essential components in controlling the two language systems for a bilingual because bilinguals, in order to fluently perform in each language, are required to rapidly monitor the context of the

language and switch between two representations (Bialystok, 2007). Therefore, it has been postulated that the need of bilinguals to consistently switch and control two languages during speech production may exert beneficial effects on their attentional control (Costa et al., 2008; Prior & Macwhinney, 2010).

Attentional control, also known as “endogenous attention”, refers to an individual's capacity to choose what they pay attention to and what they ignore (Astle & Scerif, 2009). Top-down attentional mechanism requires individual to choose what they attend to and voluntarily allocate their attention (Park & Smith, 1989). Therefore, it can be concluded that optimal performance by bilinguals in tasks that engage attentional control (e.g. Costa et al., 2008; Kapa & Colombo, 2013) may also suggest greater top-down activation in bilinguals.

Several studies have revealed superior performance by bilingual adults (e.g., Soveri, Rodriguez-Fornells, & Matti, 2011) and bilingual children (e.g., Bialystok, 1999; Kapa & Colombo, 2013) compared to their monolingual peers on cognitive tasks that require attentional control. Costa and his colleagues (2008) examined attentional control in bilingual and monolingual adults through the attentional network task (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). This task is supposed to evaluate different attentional networks including orienting and monitoring. Participants are visually presented with a row of five horizontal black lines with arrows pointing leftward or rightward. The target, leftward or rightward arrowhead, is located in the center. The target is flanked on either side by two arrows pointing in the same direction (congruent condition) or in the opposite direction (incongruent condition), or by lines (neutral condition). Participants were required to identify the target's direction by

indicating with a key press the direction it faces. The results revealed that bilingual participants were not only faster in performing the task, but also more efficient in attentional control by exhibiting a reduced switching cost between the different type of trials compared to monolinguals.

Similar to the observed bilingual advantage in attentional control in adults (Costa et al., 2008), bilingual children have also exhibited superior performance in attentional control in the children's Attentional Network Task (Kapa & Colombo, 2013). The task is similar to the adults' version but the stimuli are fish pointing in one of the two directions. Children's task was to "feed" the target fish by pressing one key for the left direction and a different key for the right direction. As in the finding with adults (Costa et al., 2008), bilingual children generally responded faster or more accurately than their monolingual peers (Kapa & Colombo, 2013). Overall, the results from these studies suggest that bilinguals are faster and more efficient in controlling attentional switching.

Further evidence for bilinguals' greater ability in attentional switching control that specifically requires top-down processing comes from a study in which monolingual and bilingual adults performed a task switching paradigm (Prior & Macwhinney, 2010). In the task-switching paradigm, participants are required to alternate between two tasks; selecting accurate responses requires performers to switch their attention. Although the task to be performed is cued on every trial and may indicate bottom-up activation, efficient performance requires voluntary internal switching of task-set configurations (Prior & Macwhinney, 2010) that is suggestive of applying top-down mechanism. Bilinguals outperformed their monolingual peers,

suggesting that experience in switching between languages may contribute to increased efficiency in top-down attentional switching.

The key element of the bilingual cognitive advantage in top-down attentional control may emerge as a result of consistent attentional switching between two languages to direct the attention to the target language. However, it is imperative to realize that the source of cognitive advantages in bilinguals also cannot be attributed to a single process or an individual component (Bialystok, 2015); rather the ongoing experience in switching between two languages may engage an integrative system that can be responsible for boosting cognitive abilities including attentional switching.

It may be assumed that bilinguals' cognitive advantage including attentional switching emerges as a result of competition between languages during speech. However, the superior performance by 7 month-old bilingually-exposed infants compared to monolingually-exposed infants (Kovacs & Mehler, 2009a) challenges this assumption by raising the following question: How do bilingually-exposed pre-verbal infants with no experience in producing language display top-down attentional control when compared to monolingually-exposed infants? To be more specific, if not language, what factor could lead to processing differences that boost top-down attentional control in bilingually-exposed infants?

### **Bilingual Exposure and Infants' Attentional Mechanism**

Bilingual superior performance in tasks that engage attentional mechanism has been also observed in "crib bilingual", infants who are exposed to bilingual environment (e.g. Kovacs & Mehler, 2009; Byers-Heinlein, Burns, & Werker, 2010; Sebastian-Galles, Albareda-Castellot, Weikum, & Werker, 2012). One possible

explanation for higher performance in attentional tasks by crib bilinguals or bilingually-exposed infants, compared to monolingually-exposed infants, is that bilingually-exposed infants also experience attentional switching in their dual-language environment.

In a monolingual environment, infants detect and learn the regularities that characterize a single language, but a dual-language environment requires infants to simultaneously detect and learn the regularities of two languages; infants must recognize both languages as native while continuing to discriminate between them (Byers-Heinlein et al., 2010). Consequently, some researchers believe that the observed cognitive advantage in bilingually-exposed infants, similar to adult bilinguals, stems from facilitation of attentional allocation as a result of discriminating between two simultaneously-presented languages (Sebastian-Galles et al., 2012). In other words, the cognitive attentional advantage in bilingually-exposed infants is derived from monitoring involving attentional switching process (Costa et al., 2009).

Empirical support for this assumption comes from studies of infants processing a salient stimulus. The capacity of infants to discriminate between languages when watching silent video clips of talking faces was assessed (Weikum, Vouloumanos, Navarra, Soto-Faraco, Sebastián-Gallés, & Werker, 2007). The results showed that 6 month old but not 8 month old monolingually-exposed infants were able to differentiate their native (English) language from an unknown (French) language. In contrast, bilingually-exposed infants from French-English homes succeeded in discriminating between English and French at both 6 and 8 months of age.

Similarly, in another study (Sebastian-Galles et al., 2012), 8-month-old Spanish-Catalan bilingually- and monolingually-exposed infants were presented with the same silent video of a face reading sentences in English or French. Again, bilingually-exposed infants excelled in detecting the switch between languages from French to English or vice versa by using visual cues alone; all monolingual infants failed to notice the switch between these languages. Bilingually-exposed infants maintain an overall advantage in visually discriminating between two languages even if they have not heard either language spoken (e.g. Weikum et al., 2007; Sebastian-Galles et al., 2012).

Talking faces are among the most dynamic and salient stimuli available to infants, and the facial movements accompanying speech may influence infants' perception. Bilingually-exposed infants, compared to their monolingually-exposed peers, may pay special attention to social partners because bilingual infants have a greater need to attend to a partner's characteristics (e.g., culture, language) to select appropriate expectations for the interaction. Furthermore, compared to monolingual children, bilingual children allocate more attention to an interaction partner's referential gestures (Yow & Markman, 2011). Therefore, increased monitoring and attending to the dynamic communicative environment may give bilingually-exposed infants an advantage over monolingually-exposed peers in attentional processes.

Overall, these studies raise the possibility that the observed advantage in attentional mechanism in bilingually-exposed infants has been boosted through consistent switching attention to two distinct sets of sounds, structures, and facial

configurations that create novelty and attract attention to subtle environmental differences (Bialystok, 2015).

Very few published studies, so far, (e.g. Kovac 2009a; Schonberg, Sandhofer, Tsang, & Johnson, 2014) have addressed the implications of bilingual input in infants' visual attentional switching relying solely on visual stimuli and independent of linguistic cues.

In one of these studies (Schonberg et al., 2014), bilingually- and monolingually-exposed infants from a broad age range, 3 to 15 months, were examined to see whether they exhibited differences in visual attention by measuring their "looking behavior" that was defined as making saccades between several objects in rapid succession and quickly scanning the environment. It was predicted that bilingually-exposed infants compared to monolingually-exposed infants make more saccadic eye movements between several objects and quickly scan the objects, indicating that bilingually-exposed infants exhibit a broader or more general visual attention whereas monolingually-exposed infants would make fewer saccades, focusing on only a small number of objects or screen locations. Higher saccade amplitude or frequency would indicate an ability to attend to visual stimuli more broadly and therefore suggest better visual attention. In a series of experiments, infants attended to visual features in social, non-social, and combined social and non-social stimuli and their saccadic eye movements were measured. Results revealed no significant difference in saccade amplitude (size) or frequency between two groups of infants. Therefore, the results indicated that the exposure to dual language environment did not appear to affect infants' visual attention.

Nevertheless, previous studies have reported superior attention of bilingually-exposed infants compared to their monolingual peers (e.g., Weikum et al., 2007; Werker & Byers-Heinlein, 2008; Sebastian-Galles et al., 2012). However, the tasks in these studies were specifically language-related, including visual speech discrimination (e.g., Weikum et al., 2007; Sebastian-Galles et al., 2012) and language acquisition (e.g., Werker & Byers-Heinlein, 2008) and were not independent of linguistic cues. In contrast, Kovács et al (2009a) examined attentional switching in bilingually- and monolingually-exposed infants using stimuli that were independent of linguistic cues and were mostly dependent on visual cues.

**Kovács' Study: Kovacs & Mehler (2009 a) Cognitive gains in 7- month-old bilingual infants.**

In an attempt to explore the impact of bilingual environments on the allocation of attentional mechanisms, Kovács et al. (2009a) conducted a study in which 7-month-old bilingually- and monolingually-exposed infants learned to respond to a speech or visual cue and to anticipate a reward on one side of a screen. Infants were presented with a speech cue in experiments 1 and 2 and visual cues in experiment 3. In experiment 1, the speech cues consisted of nonsense words containing 3 syllables. In experiment 2, the speech cues had a repetitive structure in the pre-switch phase (i.e., AAB as in le-le-mo) and a different repetitive structure in the post-switch phase (i.e., ABB as in le-mo-mo). After the offset of the cue, the anticipatory period (1 second) began and was followed by the appearance of a visual reward on one side of the screen. The reward appeared on one side of the screen during pre-switch (9 trials) and the opposite side of the screen during post-switch (9 trials).

Using anticipatory eye movements as a measurement, the researchers found that both groups of participants increased anticipatory looks to the target's location during the pre-switch phase (Kovács et al., 2009a). However, bilingually-exposed infants made more correct anticipatory eye movements toward the target during post-switch suggesting not only greater attentional switching but also higher ability to apply top-down process required to make correct anticipatory eye movement.

**Limitation.**

There are methodological issues with this study that render the results inconclusive. First, the target was displayed on the screen in a predictable pattern following a predictable sequence of cues. The target always appeared on the same side of the screen in the same sequence during both pre-switch and post-switch. Infants could simply be responding based on a rhythm of stimulus presentation rather than responding based on a top-down attentional expectation. Thus, infants' switching response may have been reactive- that is occurring in response to the repeated presentation itself as opposed to anticipation. In the current study, randomizing the sequence of predictable cues eliminated this methodological problem.

The second problem with Kovács et al.'s (2009a) method is the presentation of two different types of cues, visual and auditory. Including multiples types of stimuli may have interfered with infants' responses to the target. In our study, only visual stimuli were used.

The final limitation of Kovács et al.'s (2009a) study design is the inadequate number of trials in both, pre-switch and post-switch, each phase consisting of only 9 trials. Given researchers' limited control over infants' movements during the

experiment, it is likely that their eye tracker failed to record infants' eye movement due to sudden head movement. This would lead to a limited number of trials to code and analyze. The volume of data may have limited the reliability of the findings. In our research, this limitation was addressed by including an adequate number of trials.

### **The Present Study- Bilingual Exposure and Infants' Attentional Switching**

Considering the vital role of attentional switching in cognitive tasks (Posner & Rothbart, 2007; Rueda, Posner, & Rothbart, 2005) and lack of research on infants' attentional switching, we investigated attentional switching in infants as a function of exposure to second language using a task that relied solely on visual stimuli. Our research was motivated by the following question: Does exposure to dual-language environment facilitate infants' attentional switching?

To address our question, if infants' attentional switching is facilitated by experience with dual-language environment and by continuous switching between two languages, then bilingually-exposed infants compared to monolingually-exposed infants, should display higher efficiency in switching their attention from cue-target association rule in pre-switch to post-switch, where we reversed the cue-target rule. Therefore, the hypothesis was that bilingually-exposed infants will exhibit more correct anticipatory eye movements during post-switch.

## Method

### Participants

Data were collected from 16 infants (7 bilingually-exposed and 9 monolingually-exposed) between the age of 6 to 7-month-old. Infants in both samples were drawn from middle to upper socioeconomic status (SES) families. An additional 29 infants participated, however we had to eliminate them from the final data because these infants did not provide us with sufficient data due to crying, low compliance (i.e., inattentive, or looked at other spots out of the screen's zone), or experimenter's failure to record data within limited time that the infant was attentive.

Participants were recruited from a mailing list supplied by a Toronto-area company (Z Retail Marketing Inc., Toronto, Canada). Only infants who were born at full term and were healthy with no apparent visual, neurological or other abnormalities were examined. Informed consent was obtained from the parent of each infant.

### Paradigm

Infants were presented with a paradigm called the *visual expectation cueing paradigm* (VExCP) (Baker, Tse, Gerhardstein, & Adler, 2008), a modification of the *visual expectation paradigm* (VExP) (Haith, Hazan, & Goodman, 1988). In the VExCP, infants saw images that were predictably displayed on the left or right side of a computer screen, and infants' anticipatory eye movements in each trial were measured (Adler & Haith, 2003; Haith et al., 1988; Haith & McCarty, 1990; Wentworth & Haith, 1992). There were two different cue stimuli presented randomly in the center of the screen, each of which predicted a target stimulus appearing on either the left or right side of the screen. After a series of trials using the initial cue stimulus-target rules, the

rules were switched. In post-switch trials, the cue stimulus that previously signaled a left target instead signaled the presentation of the right target and vice versa. In order to correctly anticipate the target's location after the rules change, infants must be able to switch their attention in a top-down manner. If infants' top-down attentional control is facilitated by experience with a bilingual environment, then bilingually-exposed infants should display a greater capacity for attending and efficiently adjusting to the rule switch than their monolingually-exposed peers.

### **Stimuli and apparatus**

The cue and target stimuli were computer-generated graphic images and all subtended a  $4.5^\circ$  visual angle. The cue stimuli were circle (bulls-eye) and square (checkerboard) and the target stimulus was a computer-generated graphic image of a star (see Fig. 1). The stimuli were presented on a 19-inch LCD color monitor with 1024 · 768-pixel resolution, a refresh rate of 75 Hz, and an 8 bit/pixel gray scale. The positioning of the cue images were randomly selected for each trial, with the constraint that images fall within a  $\pm 5^\circ$  window around visual center. The target stimulus was presented  $5^\circ$  to either the left or right of visual center.

Infants were laid supine in a specialized crib and viewed the stimuli on a monitor that was situated 48 cm overhead. Between the infant and the monitor was a 30.78 cm infrared-reflecting, visible-transmitting mirror that allowed the infant a completely unobstructed view through the mirror of the stimuli on the monitor. A remote, pan-tilt infra-red eye tracking camera (Model 504, Applied Science Laboratories [www.a-s-l.com], Bedford, MA) using bright pupil technology, also was placed overhead, recording the participant's eye movements via reflection in the infrared mirror at a

temporal resolution of 60 Hz (see Fig. 2). Infrared light emitting from diodes on the camera was reflected off the infrared mirror on to the infant and then back from the infant's retina through the pupil producing a backlit white pupil. In addition, the infrared light produced a point reflection from the corneal surface of the eye. The relation between the corneal reflection and the centroid of the back-lit pupil was used to calculate the eye fixation position via proprietary ASL software. The eye-tracker was calibrated by having the infant look at a stimulus (concentric squares that loom in and out) presenting successively at known locations on either side of the screen. All subsequently recorded eye tracker values were filtered through the calibration file to produce measures of eye position data (Baker et al, 2008).

The experimental session and timing of the stimuli was programmed in Presentation Version 9.0 (Neurobehavioral Systems, Albany, CA; <http://www.neurobs.com>) running on an IBM computer (Baker et al, 2008). The sequence of stimulus presentation was based on a cueing paradigm modified from the VExp (Haith et al., 1988) and was somewhat similar to a paradigm previously used to study infants' categorization abilities (McMurray & Aslin, 2004) and Contour integration by 6-month-old infants (Baker et al, 2008). The experiment was designed so that on each trial a circle (bull's-eye) or square (Checkerboard) was randomly presented in the visual center of the monitor. The circle (bull's-eye) or square (Checkerboard) served as a cue for the subsequent presentation of a target (Star) either 5° to the right or left of visual center, which was counterbalanced across infants. Regardless, for each cue image, its relation with a specific target location was predictable.

## **Procedure**

Each trial began with the presentation of a cue for 2000 ms followed by a cue-target interval of 750 ms during which the monitor was blank. The cue-target interval was followed by the appropriate target (e.g. left side of the screen for circles, right side for squares), which appeared and stayed on the screen for 1500 ms. Finally, the trial ended with an inter-trial interval of 500 ms, after which the next trial began (see Fig. 3).

During the experiment, infants saw a total of 60 trials. The first 30 trials called pre-switch during which the cues, circle (bull's-eye) and a square (checkerboard) predicted the target (star) on the right and left respectively. During a post-switch phase, also including 30 trials, infants viewed the same cues and target stimuli but with a cue-target spatial predictability opposite to that presented during the pre-switch phase (Baker et al, 2008). Thus, during post-switch, the cues, circle (bull's-eye) and a square (checkerboard) predicted the target (star) on the left and right respectively. In addition, the sides where the cues first appeared were counterbalanced across infants (see Fig. 4).

## **Data analysis**

The raw digital data recorded by the eye tracker were imported into a MATLAB toolbox called ILAB (Gitelman, 2002) for subsequent analysis. The ILAB toolbox software was used to analyze eye movements. The ILAB software allowed us to separate out and display the horizontal and vertical components of the eye movement, on a trial-by-trial basis. Moreover, ILAB displayed the scan path of the eye on a trial-by-trial basis and thereby provided us with the information to determine the nature of the eye movement (direction and distance) relative to the stimuli.

## Data Reduction

In order to be included in final data sample analysis, an eye movement needed to meet the following criteria. First, an eye movement, in order to be considered as anticipatory, should have occurred after the offset of the cue until the first 133 ms after onset of the target. This latency value has been determined as the anticipation cut-off because based on previous study (Canfield, Smith, Brezsnyak, & Snow, 1997), 6-month-olds cannot make eye movements in reaction to the onset of stimulus faster than 133 ms. If the eye movement occurred 133 ms after picture onset until picture offset, it was considered reactive in nature and its latency was determined. Second, in order for an infant's data to be included in the final sample, they must have looked at the stimulus on a minimum of 65% of the pre-switch trials or 18 trials of the 30 trials (e.g. Adler & Haith, 2003; Adler & Orprecio, 2006) and on a minimum of 50% of the post-switch or 15 trials during post-switch. Third, the eye movement to the target must have traced a path that is more than 50% of the distance between the cue and the target. This was assessed by analysis of the infant's scan path compared to the image. The 50% criterion has been used in previous studies using 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. Finally, The eye movement should have occurred within  $\pm 5^\circ$  from the cue image presented in visual center and the target stimulus that was presented  $5^\circ$  to either the left or right of the cue image in visual center. Infants' eye movement data were analyzed in terms of one dependent measure; A correct anticipation measure was analyzed in terms of the percent of all anticipations that correctly localized target locations.

## Results

### Total Percent Correct Anticipations during Pre-switch versus Post-switch

Based on previous studies (e.g. Baker et al., 2008), infants were expected to be able to learn that a particular central cue predicted which side on which the target stimulus will appear and exhibit correct anticipatory eye movements (EM) to that target during pre-switch. During the post-switch, when the cue stimulus predicted that the target appeared on opposite side as during the pre-switch, infants needed to switch their attention to learn and then correctly anticipate the target on the basis of the new cue stimulus-target association.

To examine infants' performance during pre-switch relative to the post-switch phase, a 2 x 2 repeated-measures ANOVA was conducted on infants' correct anticipations, with Language (monolingually- versus bilingually-exposed) as the between-subject variable and Phase (pre-switch versus post-switch) as the within-subject variable (see Table 1 for mean values). This analysis revealed that the main effect of Language,  $F(1, 14) = 0.01, p = .922$ , was not significant, indicating that infants' mean correct anticipations did not differ as a function of their language environment. The main effect of Phases,  $F(1, 14) = 0.05, p = .822$ , was also not significant, indicating that infants' mean correct anticipations was not affected by the two Phases. The interaction of Language and Phases was also not significant,  $F(1, 14) = 0.99, p = .336$ , indicating that neither monolingually- nor bilingually-exposed infants made significantly more correct anticipatory EM across two Phases (Figure 5 ). This analysis, however only assesses whether there were differences over either the entire experimental session or over each entire phase. Whether there was a difference between

the two groups in learning the cue-target rule across trials in each phase and whether there was a differences in learning the new cue stimulus-target association in the post-switch in relation to pre-switch phase could not be assessed.

### **Bin Analysis (Split data into first, middle, last 10 trials in each phase)**

#### **Total Percent Correct Anticipations in the First, Middle, and the Last 10 trials during Pre-Switch**

To assess if bilingually-and monolingually-exposed infants show any changes in their performance across trials during pre-switch, the data from pre-switch was split into three bins including the first, middle and the last 10 trials (Figure 6). Repeated-measures two-way ANOVA was conducted on infants' correct anticipations, with (Language) as the between-subject variable and Bins (first, middle, last 10 trials in pre-switch) as the within-subject variables (see table 2 for mean values). Overall, There was no significant main effect of Bins in pre-switch,  $F(2, 28) = .32, p = .078$ . There was also no significant main effect of Language,  $F(1, 14) = 0.31, p = .587$ , or interaction effect,  $F(2, 28) = 0.57, p = .571$ .

#### **Total Percent Correct Anticipations in the First, Middle, and the Last 10 trials during Post-Switch**

To assess if bilingually-and monolingually-exposed infants show any changes in their performance across trials during post-switch, similar to the analysis in pre-switch, the data from post-switch was split into three bins including the first, middle and the last 10 trials (Figure 7). Repeated-measures two-way ANOVA was conducted on infants' correct anticipations during post-switch, with (Language) as the between-

subject variable and Bins (first, middle, last 10 trials in post-switch) as the within-subject variables (see table 3 for mean values).

There was a significant main effect of Bins in post-switch,  $F(2, 28) = 3.61, p = .040$ . However, there was no significant main effect of Language,  $F(1, 14) = 0.96, p = .345$ . There was also significant interaction effect,  $F(2, 28) = 3.22, p = .055$ . Therefore, a pairwise comparison was conducted to determine in which Bins during post-switch, two groups of infants behaved differently. There was only a significant mean difference in the last bin (last 10 trials) during post-switch between monolingually-exposed infants ( $M = 38.9, SE = 41.7$ ) and, bilingually-exposed infants ( $M = 82.9, SE = 25.5$ ),  $p = .028$ . There was no significant mean difference in the first bin (first 10 trials) during post-switch between monolingually-exposed infants ( $M = 75.9, SE = 26.8$ ) and bilingually-exposed infants ( $M = 78.6, SE = 30.4$ ),  $p = .856$ . Also, there was no significant mean difference in the middle bin (middle 10 trials) during post-switch between monolingually-exposed infants ( $M = 52.8, SE = 41.2$ ) and bilingually-exposed infants ( $M = 35.7, SE = 34.9$ ),  $p = .396$ .

**Total Correct Anticipations in (the last 10 trials in pre-switch) versus all bins (first, middle, last 10 trials) in post-Switch**

The previous analyses did not assess the impact of the relation switch on infants' performance relative to their performance prior to the switch. To this end, infants' performance after switching the cue-target relation in the post-switch phase was compared to their performance immediately prior to the switch at the end of the pre-switch phase. A 2 x 2 repeated-measures two-way ANOVA was conducted on infants' correct anticipations with Language (monolingually- versus bilingually-

exposed) as the between-subject variable and Phases (last10 trials in pre-switch versus all bins in post-switch) as the within-subject variables.

There was no significant main effect of the last 10 trials in pre-switch versus the first bin (first 10 trials) in post-switch,  $F(1, 14) = 1.86, p = .194$ . There was also no significant main effect of language,  $F(1, 14) = 0.06, p = .811$ . Also, there was no interaction effect,  $F(1, 14) = 0.47, p = .505$ . Also, there was no significant main effect of the last 10 trials in pre-switch versus the middle bin (middle10 trials) in post-switch,  $F(1, 14) = 2.85, p = .114$ . There was no significant main effect of language,  $F(1, 14) = 0.96, p = .344$ . Also, there was no interaction effect,  $F(1, 14) = 0.10, p = .757$ . Finally, there was no significant main effect of the last 10 trials in pre-switch versus the last bin (last 10 trials) in post-switch,  $F(1, 14) = 0.08, p = .777$ . However, there was a significant main effect of Language,  $F(1, 14) = 5.99, p = .028$ . There was no interaction effect,  $F(1, 14) = 2.73, p = .121$ . Overall, the results suggest that towards the end of post-switch (see figure 7), bilingually-exposed infants learned the new reversed cue-target rule significantly higher than monolingually-exposed infants.

## **Discussion**

The present study was designed to address the following primary question regarding the effect an infant's language environment has on his/her allocation of attentional resources and learning: Is infants' attentional switching facilitated by mere exposure to a dual-language environment?

As we postulated if exposure to two different languages and switching attention between the two set of sounds facilitate the allocation of attention, then bilingually-

exposed infants, compared to monolingually-exposed infants, would display more efficient attentional switching by revealing a greater number of correct anticipatory eye movements to visual stimuli.

Both bilingually- and monolingually-exposed infants made fairly equal correct anticipatory eye movements during pre-switch, indicating that both groups learned the cue-target rule relatively equally during pre-switch. However, we observed a significant behavioral difference between the two groups' performance in the post-switch phase. Bilingually-exposed infants could successfully learn the new rule of cue-target during post-switch and update their anticipations accordingly, whereas monolingually-exposed infants did not demonstrate such learning during the trials of post-switch.

### **The Possible Source of Advantage in Attentional Switching**

An important question to arise from the current findings is why mere exposure to a bilingual environment may lead to an advantage in attentional switching? Here we address two possibilities. First, it is possible that the bilingual environment imposes and therefore improves the efficiency in attentional switching to a greater extent compared to monolingual environment. Facing two different sets of sounds in two languages, bilingually-exposed infants are mandated by the nature of their environment to distinguish these two languages, and in doing so, it requires shifting attention consistently from one to another. The consequence of managing attention across bilingual input has been linked to advantage in mechanisms, such as inhibitory control, that are engaged in attentional control (Bialystok, 2001; Kovacs & Mehler, 2009a, 2009b). Therefore, the mere exposure to bilingual input and the force of switching attention between two different sources may improve attentional control, analogous to

the ways in which effects of dual-language exposure have been assumed to enhance inhibitory control.

Second, it is possible that linguistic diversity in the bilingual environment encourages the detection of novelty and eventually leads to enhanced visual attentional control. Although speculative, the broader sociocultural environment of the bilingual child may encompass more contrast than that of the monolingual child (Singh et al., 2014). Bilingually-exposed infants are faced with two contrasting sets of sounds, structures, speakers, and facial configurations. Contrasts create novelty (Bialystok, 2015), attracting more attention and possibly requiring more intense attentional control in bilingually-exposed infants while switching attention between the two languages. This account differs from the perspective that holds inhibition of non-target language and resolving conflict is responsible for attentional advantage in bilingual individuals. Infants are not resolving conflict in the process of inhibiting the non-target language in order to produce the target one, but they discriminate two sets of sounds that differ and require attentional processing to distinguish.

### **Disruption in Infants' Performance**

We expected to observe a decline or disruption in infants' performance immediately after reversing the cue-target rule in the beginning or the first 10 trials during post-switch phase. Surprisingly, both groups' performance declined in the middle of the post-switch phase instead of the first 10 trials. Consequently, this disruption in their performance led to a drop in their number of correct anticipatory eye movements during the middle of the post-switch. Interestingly, this drop in making

correct anticipations was only significant for bilingually-exposed infants and may be explained by Grossberg's (1995) attention model.

According to Grossberg's (1995) attention model, encountering novel events that do not match an existing expectation elicits an increase in the allocation of attentional resources in order to integrate the novel information into the existing expectation. Consequently, the increased allocation of attentional resources gradually, and not suddenly, drops over events subsequent to the novel event, leading to decreased levels of anticipatory performance over time and events. The observed disruption in infants' anticipatory behavior by novel events in a study by Adler and Haith (2003) supported Grossberg's (1995) information-processing account of expectations and anticipations. In the study by Adler and Haith (2003), 3-month-old infants were presented with a spatially predictable alternating (left-right) sequence of varying pictures and exhibited greater anticipatory response to the pictures on the one side that always appeared with the same color combination (invariant color side) than to the other side where the pictures appeared with any of the 4 possible colors (varied color side). When infants were occasionally presented with a completely novel color combination on the invariant side, infants distinguished these events by exhibiting an increase in anticipation of these novel events indicating an increased level of attentional allocation. The increased allocation of attentional resources steadily dropped to events that followed the novel event, leading to decreased levels of anticipatory performance in these subsequent events.

In terms of the current study, perhaps bilingually-exposed infants' sudden significant disruption in making correct anticipatory eye movements could be attributed

to a mechanism similar to that proposed by Grossberg (1995). Bilingually-exposed infants consistently receive novel linguistic input. As it has been shown with the study with 3- and 4-year-old children (Yow & Markman, 2011), bilingual children are better than monolingual children at using referential gestures such as gaze direction because bilingually children have to constantly monitor the novel and dynamic context to understand the speaker and to respond appropriately. We suggest that similar to bilingual children, bilingually-exposed infants also experience an increase in the level of their attentional allocation that is elicited by the nature of their linguistic environments. Consequently, faced with a novel cue-target rule, bilingually-exposed infants habitually showed an initial increased level of attentional allocation to the novel event. This subsequently wanes and leads to a decrease in the number of correct anticipations they made during post-switch.

Nevertheless, following the disruption in their anticipatory eye movements, during the last 10 trials of the post-switch phase, only bilingually-exposed infants could recover their performance by displaying a significantly greater number of correct anticipatory eye movements relative to monolingually-exposed infants. The superior performance by bilingually-exposed infants just towards the end of our experiment raises the following question: If exposure to a bilingual environment facilitates top-down attentional control then why did such efficiency appear with delay?

### **Do “Crib-Bilinguals” Behave Like “Experts”?**

In Kovacs’ study, infants did not show delay in their performance that could be due to the following reasons. First, there were only 9 trials in each phase, so the entire experiment was not long enough to reveal any delay. Second, whereas the mean age of

infants in Kovacs' study was 7 month and 22 days, the mean age of the infants in the current study was 6 month and 18 days. According to a number of visual attention developmental models, neural and attentional mechanisms necessary for top-down activation do not show full functionality until at least 6 months of age (Atkinson, 1984, 2000; Braddick & Atkinson, 2011; Johnson, 1995, 2002). Therefore, the observed delay in our infants' response could be due to less neural development maturity compared to Kovacs' infants.

However, this observed delay in our study by bilingually-exposed infants in eliciting the correct response has been observed, although on a different task, in a recent study on adult bilinguals (Incera & McLennan, 2016) in which mouse tracking was used to compare the performance of bilinguals and monolinguals in a Stroop task. Participants responded to the color of the words (e.g., blue in yellow font) by clicking on response options on the screen and their movements of the mouse were recorded based on "initiation time" (when participants started the movement of the mouse) and based on "x-coordinates over time" (defined as how quickly participants moved towards the correct response). Although initiation time was longer for bilinguals than monolinguals, while comparing mouse track, bilinguals moved faster towards the correct response. The researchers explained the bilinguals' behavior by comparing them to "experts" in baseball who wait longer than novices between the moment of seeing the ball and initiating the swing. Expert ball players typically spend more time assessing the circumstances and allocate attention to "reading the pitch," a response that eventually leads to more efficient performance. The experimental evidence for this theory comes from an eye-tracking study by Shank and Haywood (1987), in which

expert baseball players were compared to beginners while watching a baseball pitch. They found that whereas beginners made eye movements to the oncoming ball prior to the pitch being released, experts fixated the anticipated release spot for approximately 150 ms then moved their eyes towards the oncoming ball. Consequently, Incera and McLennan (2016) suggested that bilinguals, due to more expert attentional mechanisms, may delay their ‘initiation time’ to move the mouse in order to more fully assess the parameters of the task and allocate attention appropriately before beginning their response.

Similarly, in the current study, bilingually-exposed infants may have similarly behaved like “experts” by delaying their response time to more fully assess and attend to the new reversed rule of the cue-target location association encountered during the post-switch phase. As a consequence of this delay, bilingually-exposed infants eventually were able to respond more efficiently than monolingually-exposed infants. This efficiency is exhibited by the bilingually-exposed infants emitting a higher number of correct anticipatory responses during the last 10 trials of the post-switch phase than monolingually-exposed infants.

### **Conclusion**

The current findings advance our knowledge of cognitive visual attention in bilingualism in important ways. First, unlike previous studies reporting “infant bilingual advantage” (Gervain & Werker, 2013; Kovacs & Mehler, 2009a, 2009b; Sebastian-Galles et al., 2012), the current paradigm does not rely on demands of language processing and engages visual cognitive processes by using nonlinguistic visual stimuli.

Second, unlike the effect of bilingual input on adults, which has been heavily centered around inhibitory control (Martin-Rhee & Bialystok, 2008), investigations into the impact of exposure to a dual-language environment on infants have been more diffuse in context and applied tasks. For instance, studies by Kovacs and Mehler (2009a, 2009b) used inhibitory control tasks, which are infant analogs to tasks that have indicated cognitive advantages in bilingual adults referred to as “bilingual advantages.” Although Kovacs’ studies (Kovacs & Mehler, 2009a, 2009b) revealing cognitive advantage in 7-month-old bilingually-exposed infants emphasized on the inhibitory control advantages, commonly declared in adults, the present study provides empirical evidence for attentional switching advantage in bilingually-exposed infants in a way that is based on tasks that are more reliable in measuring visual cognitive attentional processes than previously suggested.

The last and the most important implication is that the exhibition of superior performance during post-switch by bilingually-exposed infants may be indicative of more efficient top-down activation in bilingually-exposed infants’ attentional switching. Successful performance during post-switch requires correctly anticipating the new location of the target that needs unlearning the cue-target rule, previously learned in pre-switch, in order to learn the new cue-target rule. This process of unlearning-learning requires efficient allocating attention from pre-switch to the post-switch cue-target’s association rule.

Moreover, we postulated that anticipatory eye movements reflect a top-down process because anticipatory eye movements have to be emitted by using cognitive process when there is no stimulus perceptually available to elicit that eye movement.

We defined top-down attentional mechanism as a process that is being reflected in anticipatory eye movements. Consequently, the exhibition of significantly higher frequency in correct anticipations during post-switch by bilingually-exposed infants suggest greater capacity to efficiently switch their attention for adjusting to the new cue-target stimulus rule in post-switch. Moreover, this observed significantly superior attentional allocating or switching by bilingually-exposed infants between the two phases may suggest enhanced top-down attentional control in bilingually-exposed infants.

Our results confirm Bialystok's assumption (2015) about the source of cognitive advantage in bilinguals by expressing that observed advantage in attentional mechanism in bilingually-exposed infants may have been boosted through consistent switching attention to two distinct sets of sounds, structures, and facial configurations that create novelty and attract attention to subtle environmental differences (Bialystok, 2015).

### **Limitations / Future Investigation**

In Kovac's (2009a) study, infants were considered bilingual if they had parents with different mother tongues who addressed infants consistently in the parents' native languages and if infants had daily exposure to both languages. In our study, we used the Language and Social Background Questionnaire (LSBQ), which was originally designed for adults and children, not infants. A few questions were eliminated to make it applicable for infants. Although the current findings suggest that mere exposure to the dual-language environment might be sufficient for promoting top-down attentional control, it remains unknown how much of this attentional enhancement depends on the

amount of exposure called “Exposure dependency.” In studying bilingually-exposed infants or so-called “crib bilinguals,” exposure dependency can interfere with criteria in Language Background Questionnaire (LBQ) to define crib bilinguals (Werker, 2008) and may have impacted the findings in this study as well. Generally, language exposure of infants’ is typically determined by completion by each parent of an LBQ that consists of questions about children’s language exposure, the identity of the primary caregiver(s), the language(s) spoken by parents and/or primary caregivers when addressing the child, and the proportional use of each language (Singh et al., 2014). When studying bilingual effects on infants, monolingualism is defined as having at least 90% exposure to a first language, and bilingualism is defined as having at least 25% exposure to a second language (Pearson, Fernandez, & Oller, 1993). In many studies of crib bilinguals, responses on an LBQ could not specify the exact amount of exposure to a second language necessary to consider an infant bilingual. Consequently, criteria to define crib bilinguals can cause ambiguity in categorizing infants as monolingual or bilingual (Werker, 2008). The LBQ used in this study lacks precision in questions about secondary caregivers (e.g., grandparents) and exposure to television. Conclusively, researchers studying crib bilinguals face ongoing challenges in identifying relatively balanced bilingual infants. Therefore, designing LBQs that can precisely calculate the level of exposure to each language may be of interest for future research.

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## Appendix A: Tables

Table 1

*Mean percent correct anticipations during pre-switch versus post-switch*

Phases	Monolingual	Bilingual
Total % CA in Pre-switch	70.13 (17.61)	61.65 (29.69)
Total % CA in Post-switch	60.67 (19.49)	67.58 (20.71)

*Note.* Standard deviations are in parentheses.

Table 2

*Mean Percent correct anticipations in first, middle and last 10 trials during pre-switch*

% CA in Pre-Switch	Monolingual	Bilingual
First 10 trials	41.67 (43.30)	50.00 (50.00)
Middle 10 trials	73.52 (34.32)	52.38 (50.40)
Last 10 trials	70.08 (34.04)	60.95 (34.25)

*Note.* Standard deviations are in parentheses.

Table 3

*Mean Percent correct anticipations in first, middle and last 10 trials during post-switch*

% CA in Post-Switch	Monolingual	Bilingual
First 10 trials	75.93 (26.82)	78.57 (30.37)
Middle 10 trials	52.78 (41.25)	35.71 (34.93)
Last 10 trials	38.89 (41.67)	82.86 (25.49)

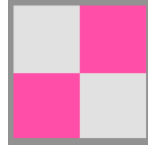
*Note.* Standard deviations are in parentheses.

## Appendix B: Figures

Cue-Circle (bulls-eye)



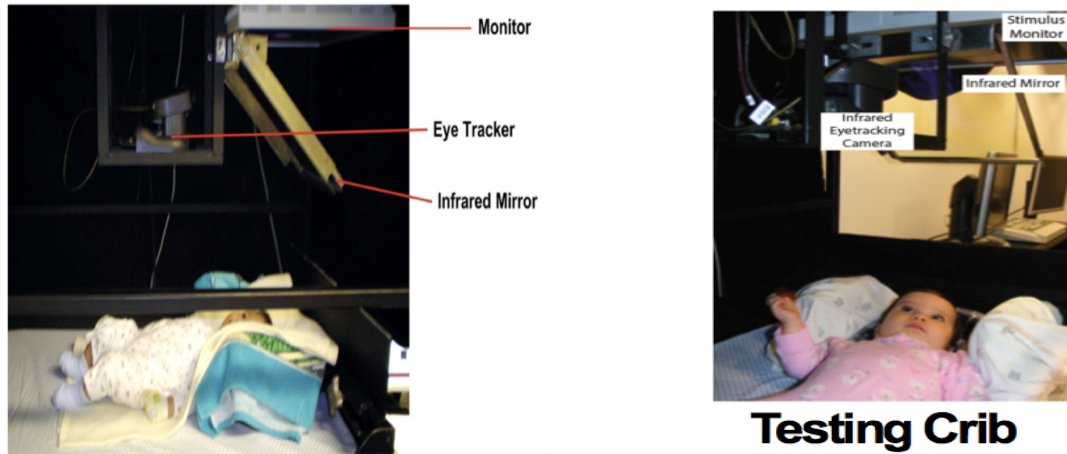
Cue-Square (checkerboard)



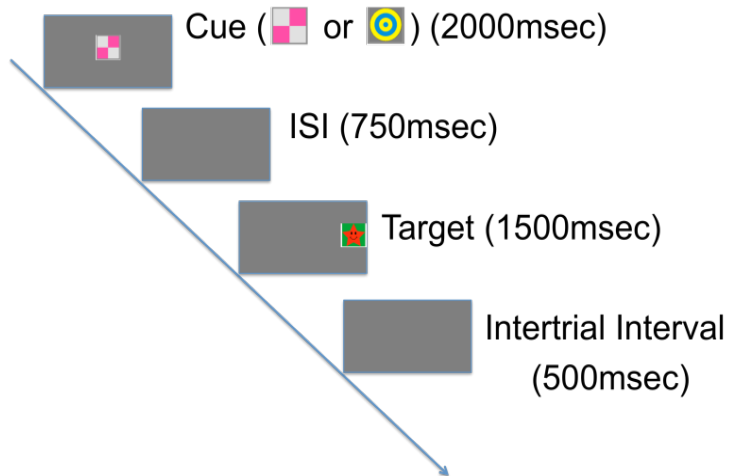
Target



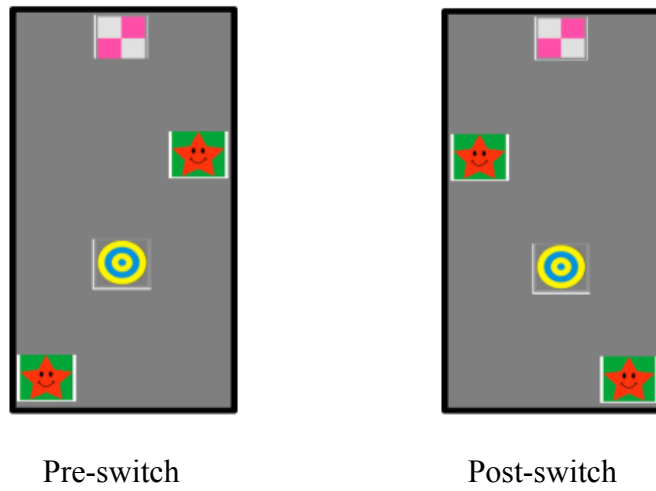
*Figure 1.* Cues and the target images for both the predictable and unpredictable conditions.



*Figure 2.* Infrared eye-tracking camera recorded the infants' pupil and eye movements throughout the experiment.



*Figure 3.* Temporal Sequence showing stimulus sequence of events over time. The infants will be first presented with a circle (bulls-eye) or a square (checkerboard) that will act as a cue to a target on either the right or left (dependent on the cue), so the target location will be predictable based on the cue image.



*Figure 4.* Visual Expectation Paradigm showing the sequence of stimuli appearing on the screen.

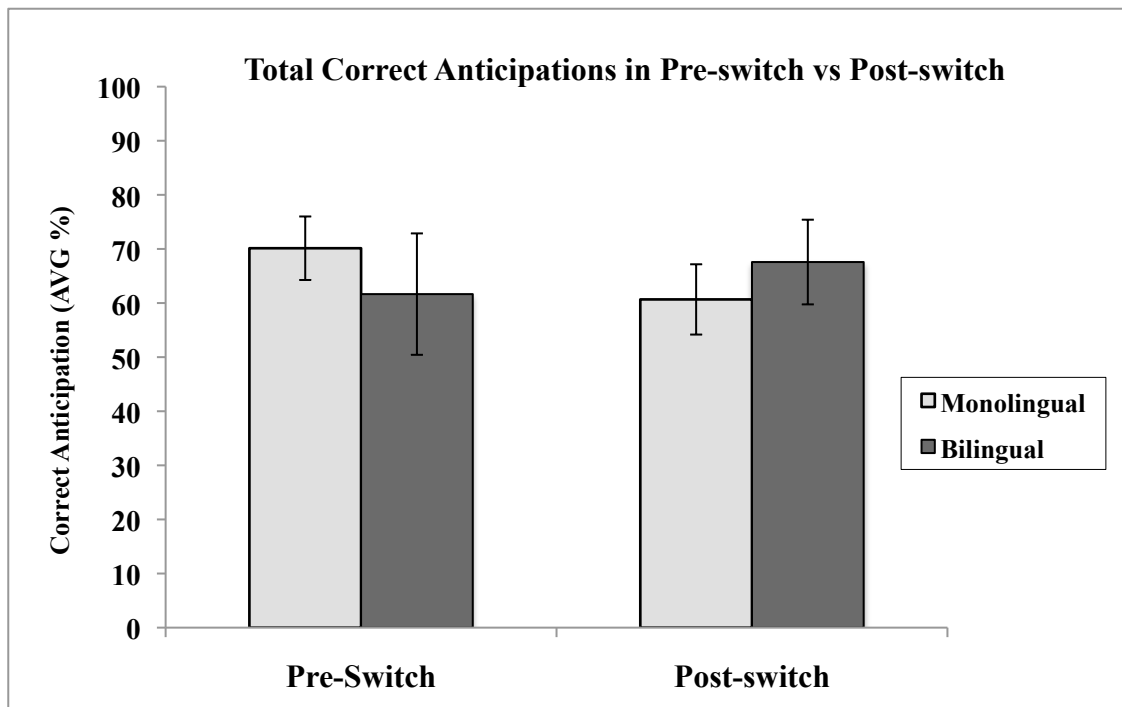


Figure 5. Mean percent correct anticipations during pre-switch versus post-switch

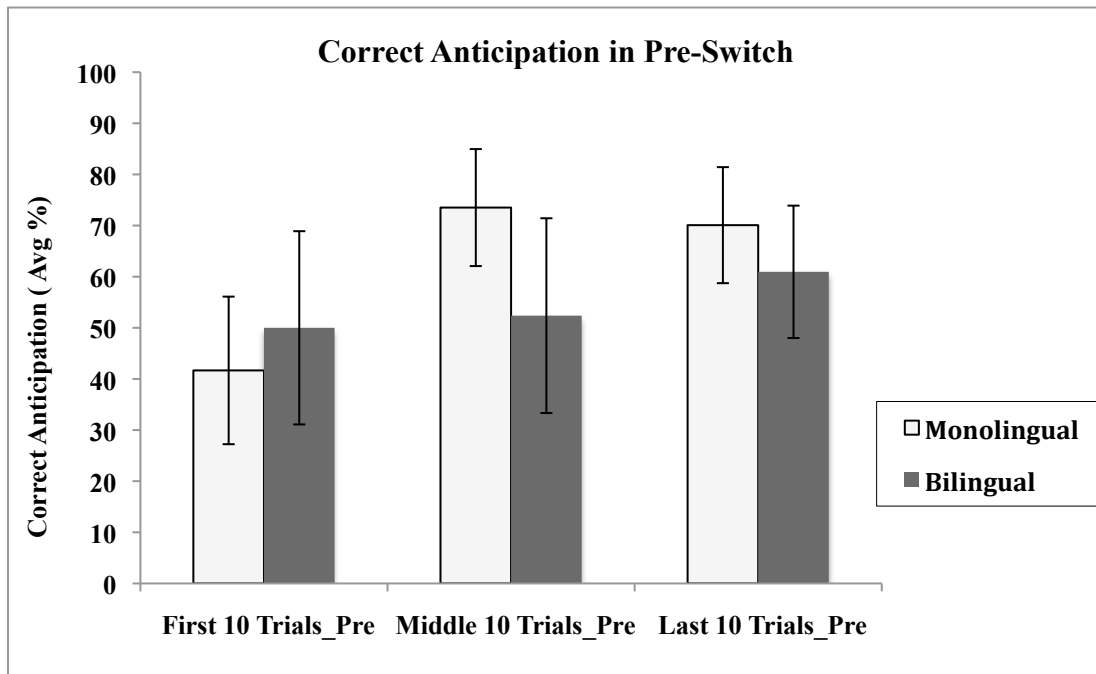


Figure 6. Mean percent correct anticipations during pre-switch.

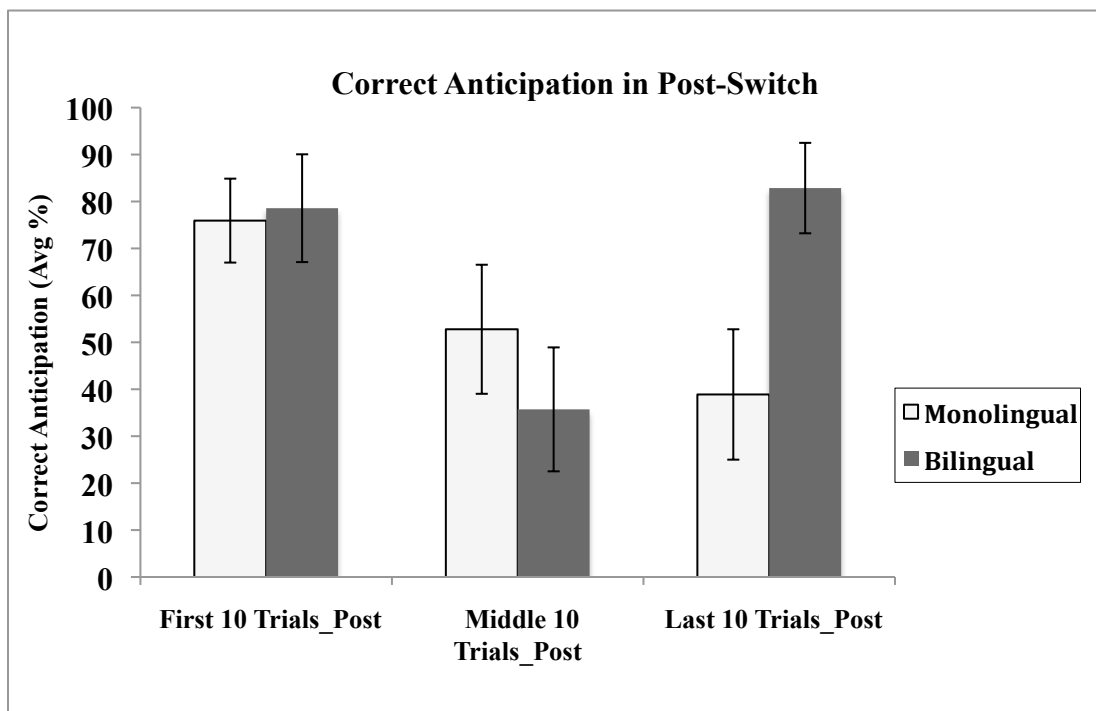


Figure 7. Mean percent correct anticipations during post-switch.

## Appendix C: The Informed Consent

**Visual and Cognitive Development Project**

5030 TEL  
 4700 Keele Street  
 York University  
 Toronto, Ontario, Canada M3J1P3  
 Tel: 416-736-2100, ext. 20036

We are required to obtain a signed consent form from the parent(s) of infants who participate in our studies. I agree to have my child, \_\_\_\_\_ (name of child), participate in a study entitled “Issues of Selective Attention and Eye Movements Across Development.”

I understand that my child will watch pictures that are displayed on a TV monitor as a means of understanding the development of selective attention, perception, and memory in young infants. The pictures are usually interesting to babies near the age of my child. During this time, the movement of my child's eyes will be made under invisible infrared light. I understand that I (child's parent) will place my child in the crib used for the study. The experimenter and I will be present at all times. I understand that the recording of my child's visual behavior may be analyzed at a later time. The potential risks to my child are few and include fatigue or mild frustration. In the event of either fatigue or frustration, the procedure, which takes approximately 5-10 minutes, will be stopped immediately. I understand that I can stop the procedure at any time during the session. The benefits of participating in this study include furthering scientific knowledge about infant's cognitive development in general.

I understand that I will receive a Album Pro coupon valued at \$15.99, as compensation for my time. I understand that I can withdraw my child from participation at any time without prejudice, that I can freely ask questions about the procedures in this study and that my child will be identified for purposes of the study by a unique code number and not by name. If I do withdraw my child, I understand that all data and information associated with my child will be destroyed by the shredding of any paperwork and the deletion of any computer files. I understand that even if I withdraw my child for any reason or refuse to answer any question, my relationship with the researcher, York University or any group associated with this project will not be affected in any way and I will still receive the Album Pro coupon. I also understand that I will receive a summary of the findings of this study once it has been completed, and only group results, no individual results will be summarized. I understand that the researchers are interested in groups of infants and that they will not disclose any information about individual infants to any person not directly associated with the study or in any publications resulting from this study. All information directly associated with my child will be kept confidential to the fullest extent allowed by law and securely stored in the locked offices of the Project and on password protected computers for a period of 5 years. After this time, all documents associated with my child will be shredded and computer files will be deleted. I understand, however, that all analyzed

data generated by my child's participation will be kept indefinitely, for the possibility of reanalysis at a later date.

I have read and understood the foregoing description of the research project. I have asked for and received a satisfactory explanation of any language or details of the study that I did not fully understand. If, at a later time, I have any questions, I may contact Scott Adler, Ph.D., at York University (416-736-5115, ext. 33389, or 416-736-2100 ext. 20036, or [adler@yorku.ca](mailto:adler@yorku.ca)) for additional information. I have received a copy of this consent form.

This research has received ethics review and approval by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Sr. Manager & Policy Advisor for the Office of Research Ethics, 5th Floor, Kaneff Tower, York University (telephone 416-736-5914 or e-mail [ore@yorku.ca](mailto:ore@yorku.ca)). My signature below indicates that I agree to have my child participate in the study and it also serves as confirmation that I will receive the coupon offer at the end of the research session.

I consent to have my child, \_\_\_\_\_ (name of child), be video-recorded during his/her participation in the study entitled "Issues of Selective Attention and Eye Movements Across Development." I understand that this video will potentially be used solely as a demonstration during presentations to disseminate this research or as teaching tool. I understand that my child's name will not be disclosed during any presentation of the video. I further understand that my refusal to have my child video-recorded will not affect my participation in this study nor will it affect my relationship with the researcher, York University or any group associated with this project.

Parent(s)' Signature(s) \_\_\_\_\_

Date \_\_\_\_\_

## Appendix D: Baby Information Sheet

## BABY INFORMATION SHEET

Study \_\_\_\_\_ ID# \_\_\_\_\_

Name \_\_\_\_\_ Parents \_\_\_\_\_

Home Address \_\_\_\_\_  
\_\_\_\_\_

Email \_\_\_\_\_

Due Date \_\_\_\_\_ Birthdate \_\_\_\_\_ Age (days) \_\_\_\_\_

Date of Visit \_\_\_\_\_

Ethnicity: Caucasian \_\_\_ African \_\_\_ Hispanic \_\_\_ Asian \_\_\_ Native \_\_\_

Other \_\_\_\_\_

Gender \_\_\_\_\_

Birthweight \_\_\_\_\_

Birth Complications \_\_\_\_\_

Was your baby born via C-Section? \_\_\_\_\_

Languages spoken at home \_\_\_\_\_

Father's Level of Schooling: High School \_\_\_ College/University \_\_\_ Post-

Graduate \_\_\_

Occupation \_\_\_\_\_ Age \_\_\_\_\_

Mother's Level of Schooling: High School \_\_\_ College/University \_\_\_ Post-

Graduate \_\_\_

Occupation \_\_\_\_\_ Age \_\_\_\_\_

Household Income \_\_\_\_\_

## Appendix E: The Language and Social Background Questionnaire (LSBQ)

Reference Code \_\_\_\_\_

	<b>Infant Cognitive Development Lab</b> <b>Dr. Scott Adler</b> Department of Psychology, York University
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**Language and Social Background Questionnaire (to be completed by parents)**

1. Today's date: \_\_\_\_\_  
   day  month  year
2. Completed by: Mother  Father  Other  (please specify) \_\_\_\_\_

**Part A – Background**The following information refers to your **INFANT**:

3. First name: _____	Last name: _____
4. Date of birth _____ day  month  year	5. Sex: _____
6. Country of birth: _____	

The following information refers to the **PARENTS**:

7. Country of birth of MOTHER: _____
If not born in Canada, when did the mother come to Canada? (Month/Year) _____
What language(s) did the mother grow up speaking? _____
List the languages known by the mother, <i>in order of fluency (most fluent to least fluent)</i> : _____
8. Country of birth of FATHER: _____
If not born in Canada, when did the father come to Canada? (Month/Year) _____
What language(s) did the father grow up speaking? _____
List the languages known by the father, <i>in order of fluency (most fluent to least fluent)</i> : _____

