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Bilingual Infants Readily Orient to Novel Visual Stimuli

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Bilingualism has been shown to modify infants' responses in a range of domains. In particular, early bilingual experience is associated with greater flexibility and openness in infant perception and learning. In this study, we investigated whether bilingual infants demonstrate more fundamental differences in how they explore their environment in ways that could contribute to greater openness. Specifically, we investigated whether bilingual infants orient more rapidly to new information. Capitalizing on a classic paradigm by Fantz (1964), monolingual and bilingual infants (5–6 months and 8–9 months) were simultaneously presented with familiar and novel stimuli. As they received increased exposure to the familiar and novel stimuli, monolingual infants demonstrated a null preference, followed by a novelty preference, as previously evidenced in Fantz's study. In contrast, an orientation toward novelty emerged more readily in bilingual infants. Characteristics of a bilingual environment that may modulate the allocation of attention toward novelty are discussed.

Public Significance Statement
This manuscript reports the findings of an investigation of how bilingually raised infants explore their visual environment. Findings demonstrate that bilingual infants orient more readily to novel (unfamiliar) information compared with monolingual infants. The study suggests that early language exposure influences how infants allocate their attention within their environment.

Keywords: bilingualism, visual memory, infancy

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Bilingual experience has been shown to have early effects on memory, perception, and learning during the first year of life. Bilingually exposed infants show greater facility with learning dual grammatical systems (Kovács & Mehler, 2009a), inhibiting responses to previously learned contingencies (Kovács & Mehler, 2009b, but see D'Souza et al., 2020; Kalashnikova et al., 2021), and discrimination of visually presented speech (Sebastián-Gallés et al., 2012). They also show greater flexibility and openness in speech perception (Petitto et al., 2012; Singh, 2018; Singh & Tan, 2021; Singh et al., 2017). Each of these associations reflects bilingual adaptations in areas of functioning that are relevant to language uptake. For example, bilingual infants are thought to benefit from the capacity for linguistic inhibition to a nontarget language while engaging with a target language. Similarly, bilingual acquisition may benefit from increased openness to acquire novel linguistic structure. For these reasons, the adaptations may reflect the optimization of infant learning systems to learning two linguistic systems.

In addition to these findings, however, recent research has attested to more basic shifts in attention and perception in bilingual infants. These more basic shifts do not link as directly to the demands of

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bilingual acquisition. In particular, bilingual experience has been associated with variation in infant visual processing. In a study conducted in Singapore, Singh et al. (2015) tested 6-month-old bilingually and monolingually exposed infants on a visual habituation paradigm. Both the monolingual and bilingual groups were heterogeneous, that is, they were learning different native languages (English, Malay, Mandarin, and Tamil). The groups were matched on maternal education, maternal income, and household income. In this task, infants viewed repeated presentations of the same stimulus (a wolf or a bear). Infants' looking time was recorded as the stimulus was presented. Speed of habituation was measured to index the efficiency with which the information was encoded (Colombo et al., 2004). After infants habituated to the stimulus, they were presented with side-by-side images of the habituated stimulus and a novel stimulus. Typically, infants who have encoded the habituation stimulus preferentially fixate the novel stimulus, demonstrating recognition memory of the habituation stimulus.

The Singh et al. (2015) study revealed two differences between bilingually and monolingually exposed infants. First, speed of habituation (as measured by the amount of attentional decrement between the first and last habituation trial and by the number of trials within which the habituation criterion was attained) was higher for bilingual versus monolingual infants. Second, during the recognition memory phase, only bilingual infants preferentially fixated the novel stimulus. Given that both groups of infants habituated to the familiarization stimulus, it may be surprising that only one group (bilingual infants) demonstrated a novelty preference to the change in stimulus. Although prior studies have demonstrated dishabituation to visual stimuli at 6 months (e.g., Ramsey et al., 2004), in the task used by Singh et al. (2015), infants were habituated to a single image and then tested on a visually similar dishabituation stimulus. In other studies, such as Ramsey et al., infants were habituated to multiple exemplars, which has been shown to facilitate categorization (Quinn, 1987) in a paired visual comparison. The task of Singh et al. was intentionally designed to be challenging in order to reveal individual differences in habituation and dishabituation. Habituation data and recognition memory data were not correlated within the Singh et al. sample, aligning with a two-factor model of habituation where habituation and recognition behaviors have different underlying bases (Colombo, 1993). The Singh et al.'s study suggests that the efficiency of stimulus encoding and the subsequent expression of recognition memory for an encoded stimulus may vary on account of bilingual exposure.

Further studies have investigated associations between bilingual experience and visual attention. In a recent study by D'Souza et al. (2020, Experiment 3), 8-month-old infants were presented with a central stimulus and a peripheral stimulus. The authors investigated the speed with which both groups of infants disengaged from the central stimulus to the peripheral stimulus. When these stimuli appeared simultaneously, the authors reported that the full sample of bilingual and monolingual infants did not differ in the speed of disengagement from the central stimulus. However, an exploratory analysis of a subsample of infants (those who provided higher quality data) revealed faster disengagement from the central stimulus in bilingual infants. In a second experiment (Experiment 4), 8-month-old infants were presented with two identical visual images side-by-side. Over the course of the trials, one of the images remained the same, while the other became progressively differentiable from the original image. The researchers measured attentional switching between the stimuli, finding that bilingual infants were more likely to switch attention between the two stimuli. However, one cannot conclude in this case that the bilingual infants were more likely to disengage from the familiar stimulus to spend more time exploring the novel stimuli because there was no evidence that either group of infants preferentially fixated the novel, changing stimuli as the task progressed, supporting the authors' claim that the task was too difficult for the infants.

D'Souza et al. (2021) investigated similar processes in monolingual and bilingual adults. The authors separated their bilingual sample by the age of acquisition of both languages, distinguishing behavioral patterns evidenced in early bilinguals from late bilinguals. Their findings demonstrated that early bilinguals were faster in disengaging from a familiar visual stimulus to a novel stimulus and at noticing visual contrast between two stimuli than late bilinguals. This study suggests that early exposure to two languages may influence how individuals process competing visual information.

More recently, Kalashnikova et al. (2021) sought to replicate previously reported inhibitory control advantages in bilingual infants reported by Kovács and Mehler (2009b). Kalashnikova et al. compared Spanish and Basque monolinguals with Spanish and Basque bilinguals at 7 months of age. In this task, infants were presented with stimuli that cued a visual reward. After learning the contingency between the cue and the location of the reward, which was a novel visual stimulus, there was a change such that the reward was predicted by different cues and appeared in a different location. Although Kalashnikova et al. did not find a bilingual effect in adapting to this change (see also D'Souza et al., 2020, Experiment 1) an unpredicted finding was that bilingual infants were more likely to fixate the novel visual reward than monolingual infants.

These studies converge on the notion that bilingualism modulates the allocation of visual attention in infancy, raising the fundamental question of why language experience might influence how infants might explore their environment. We propose two properties of bilingual environments that may make it adaptive to explore the environment more broadly and demonstrate a greater orientation toward novelty. First, bilingual infants necessarily hear less of each language than their monolingually exposed peers. However, true bilinguals are confronted with similar expectations of native proficiency in each language as monolingual learners. As a result, bilingual infants essentially have to do more with less. This may require bilingual infants to process new information more efficiently in order to compensate for reduced single-language input. As a result, familiar information may be encoded more efficiently on account of increased pressure on infants' information processing systems.

A second and related point is that bilingual infants, in encountering two different languages, are immersed in a more varied environment containing more novel information. Bilingual experience entails exposure to a greater range of sounds, words, and grammatical constructions than monolingual experience. The presence of increased novelty may lead to a reduced orientation to familiar information and to greater attention to novel information. Broader exploration in the context of increased novelty and diversity has been demonstrated in a number of tasks and domains. For example, increased racial diversity leads to heightened attention to novel races (Bar-Haim et al., 2006; Singh et al., 2022). Increased exposure to musical diversity expands the range of musical sequences that infants prefer (Hannon & Trehub, 2005). Similarly, more diverse language exposure has been associated with increased openness to linguistic contrast (Burnham et al., 2018; Graf Estes & Hay, 2015; Petitto et al., 2012; Singh, 2018; Singh & Tan, 2021; Singh et al., 2017). In order to learn from diverse environments, it may benefit learners to attend to a wider range of information to acquire underlying organization.

Past studies raise the question of whether bilingualism influences basic attentional preferences in a way that leads to greater novelty-seeking. The present study directly examined this question by capitalizing on a key observation by Fantz (1964). Fantz presented infants across different age ranges with paired visual images across a series of trials. Across the trials, one image remained constant trial-after-trial and one image varied. Infants' looking preference for the familiar (constant) image over the novel (changing) image was measured. Young infants (1–2 months) showed a null preference throughout the test session. However, older infants' preference for the familiar (constant) stimulus decreased and their preference for the novel (changing) stimulus increased as the trials progressed, suggesting an age-modulated transition in attentional preference toward novelty.

This seminal finding gave rise to a widespread assumption in infant visual attention that infants progress toward a novelty preference as they acquire greater familiarity with stimuli. This assumption has been used to explain infants' attentional preferences in various domains (e.g., Bahrick & Pickens, 1995; Courage & Howe, 1998; Roder et al., 2000; Rose et al., 1982; Thiessen, 2012). For example, Rose et al.'s (1982) study states that infants begin with a familiarity preference and only when processing becomes more advanced do they demonstrate a novelty preference. This statement is consistent with a classic model of infant visual attention (Hunter & Ames, 1988), which is often invoked to explain the conditions under which familiarity and novelty preferences arise. The Hunter and Ames (1988) model of infant visual attention, which serves as the dominant framework for understanding infant-looking behavior, posits a familiarity-to-novelty transition in visual attention. The model presumes that when presented with two stimuli—one familiar and one novel—that infants initially prefer the familiar stimulus. As they receive continued exposure, they begin to prefer the novel stimulus. Hunter and Ames further posited that three factors determine the familiarity-to-novelty transition. First, older infants are presumed to demonstrate a faster transition. Second, as familiarization time increases, infants are thought to progress more rapidly to a novelty preference. And third, if a task is difficult (e.g., processing complex stimuli), the transition from familiarity to novelty is slower.

In the current study, we sought to determine how monolingual and bilingual infants compare their preferences for familiar versus novel information. We adapted Fantz's original paradigm to determine whether this procedure—that provided the first laboratory evidence of infant visual preference—was dependent on language experience. Based on past data demonstrating (a) more rapid processing of familiar stimuli in bilingual infants (Singh et al., 2015), (b) a greater tendency to distribute attention more evenly between familiar and novel stimuli in bilingual infants (D'Souza et al., 2020), and (c) novel stimuli being more visually rewarding for bilingual infants (Kalashnikova et al., 2021), we hypothesized that bilingual infants may orient more toward continually changing stimuli on account of an increased orientation toward visual novelty. We further predicted that a novelty preference, if observed, would be related to the amount of second language exposure. This prediction came from work on a sample of infants with varying degrees of bilingual exposure and the finding that the degree of bilingual exposure was positively correlated with the amount of disengagement from a familiar stimulus to a novel stimulus (D'Souza et al., 2020). We intentionally tested infants across different linguistic environments to sample different groups of bilingual and monolingual infants. At the same time, we matched participants within and across these settings on socioeconomic status. This procedure allowed us to determine whether any effects of language group were robust against linguistic and geographic variation.

Method

Participants

Two groups of infants participated in this study from two different testing locations (total $N = 99$). The first group included infants growing up in the Basque Country in Spain who were acquiring Spanish or Basque or both in a monolingual or bilingual environment. The second group included infants growing up in Singapore who were acquiring English or Mandarin or both in a monolingual or bilingual environment. Approximately half of the infants in each location and language background group were 5–6 months old and half were 8–9 months old. Table 1 presents detailed sample size and demographic information for each infant group. Demographic information was collected via an open-ended interview. Participants' caregivers were asked for their dates of birth, language exposure, relevant medical history, and sex assignment at birth.

Infant language background was determined based on a parental Language Background Questionnaire (Bosch & Sebastián-Gallés, 2001; Molnar et al., 2014), in which parents were asked to provide details about their infants' language exposure patterns from birth until the time of the experiment. Infants were considered bilingual if they received from 25% to 75% exposure to two languages from birth and no more than 10% exposure to a third language. Bilingual infants from Spain were acquiring Spanish and Basque (21) and English and Spanish (one) (12 Spanish dominant, nine Basque dominant, one English dominant), and bilingual infants from Singapore were acquiring English and Mandarin (23) and

Table 1
Sample Size for Each Infant Group and Participants' Demographic Information

Language group	Age group	*N*	Mean age in weeks (*SD*)	Sex (F; M)	Test location (*N*)	Mean L1% (range)	Mean L2% (range)
Monolingual	5–6 months	30	15.08 (1.95)	13 F; 17 M	Spain (17); Singapore (13)	96.42 (89.8–100.0)	5.67 (0.6–10.2)
	8–9 months	23	24.20 (1.21)	13 F; 10 M	Spain (11); Singapore (12)	94.09 (89.5–100)	8.15 (5–10.4)
Bilingual	5–6 months	24	15.12 (2.40)	13 F; 11 M	Spain (13); Singapore (11)	65.93 (51.6–79.2)	33.20 (20.8–48.4)
	8–9 months	22	24.26 (1.18)	10 F; 12 M	Spain (9); Singapore (13)	64.04 (52.8–74.9)	35.51 (25.1–47.2)

Note. M = male; F = female; L1 = first language; L2 = second language.

English and Tamil (one) (17 English dominant, seven Mandarin dominant). In Spain, bilingual infants were not reported to receive any exposure to a third language, but in Singapore, bilinguals received on average 4.73% of exposure to third languages that included Cantonese, Hakka, and Hokkien. Infants were considered monolingual if they received no more than 10% exposure to a non-dominant language. Monolingual infants from Spain were acquiring Spanish (10) or Basque (18); monolingual infants from Singapore were acquiring English (24) or Mandarin (two), and were reported to have minimal exposure (<4%) to additional languages including Hokkien, Malay, Tagalog, Japanese, Korean, and Bahasa. As is typical in studies of infant bilingualism—where bilingual experience is defined in terms of amount of exposure—infants' first languages are defined as those to which they have more exposure, and second languages are defined as those to which they have less exposure. To provide context for the conditions in which the participants were raised, all infants were raised in multilingual societies with several languages in circulation. In terms of language exposure in the home, in Spain, 11 of 22 bilingual infants heard one language from each parent. In Singapore, four of the 24 bilingual infants heard one language from each parent. All other bilingually exposed infants heard multiple languages from each parent.

All infants in the final sample were reported to be in good health at the time of testing, have normal vision and hearing, and not to be at risk for any developmental disorder. Maternal and paternal education levels were used as proxies for assessing participating families' socioeconomic status. Maternal and paternal education levels ranged from a high school diploma to a doctoral degree, and the median was a university degree. Education levels did not differ significantly between the two testing locations (Kolmogorov–Smirnov test Spain vs. Singapore: maternal education $Z = .471$, $p = .980$, paternal education $Z = 1.184$, $p = .121$), or between the monolingual and bilingual samples in each location (Kolmogorov–Smirnov tests monolingual vs. bilingual: Spain, maternal education $Z = .262$, $p = 1.000$, paternal education $Z = .650$, $p = .793$; Singapore, maternal education $Z = .391$, $p = .998$, paternal education $Z = .700$, $p = .711$).

An additional 20 infants participated but were excluded from the final sample due to failure to satisfy the inclusion criteria for one of the language background groups (three), fussiness (10), failure to contribute at least one trial in a trial block (four), parental interference (one), and experimenter error (two).

All procedures were approved by the Institutional Review Boards of the two institutions where data were collected (National University of Singapore and Basque Center on Cognition, Brain and Language).

Transparency and Openness

The Institutional Review Board of the participating institutions did not allow individual data points to be stored on publicly available data repositories at the time of data collection. Stimuli, materials, and code will be made available upon request.

Stimuli

Thirty-six color images of animals from Quinn et al. (2009) were used as the experimental stimuli: 18 pictures of cats and 18 pictures of dogs, selected from Schuler (1980) and Siegel (1983). These images were used to generate 24 stimulus presentation sequences: 12 using only cat images and 12 using only dog images. For each sequence, 11 images were randomly chosen from each set. Out of these 11, for each infant, one image was randomly designated as the familiar referent and the remaining 10 as the novel referents.

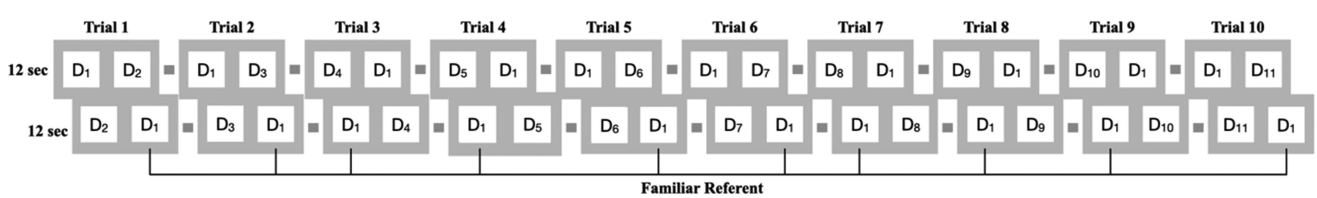
A sample trial sequence is shown in Figure 1. Trials proceeded in order from Trial 1 to Trial 10 (i.e., from left to right in Figure 1). Each infant saw a total of 10 trials. On each trial, a pair of images was presented side by side on a gray background for 24 s. The pairs always consisted of the familiar referent (i.e., D_1 in Figure 1) and one of the novel referents (i.e., D_n in Figure 1). Halfway through each trial, the location of the familiar and novel referents was switched on the screen to ensure that the infants' preference for one of the referents reflected a stimulus preference instead of a side preference. For example, on a given trial, the familiar referent would appear on the right side of the screen for the first 12 s, and on the left side of the screen for the last 12 s, or vice versa. The familiar referent started on the right side for half of the trials and on the left side for the other half. An attention-getter, consisting of an image of a centrally positioned blue square, was presented for 500 ms after every 12 s of trial presentation (i.e., before the start of each trial and before the location of the two referents was swapped within a trial). Trial duration was fixed, so each sequence had a total duration of 249.5 s (4.15 min).

Procedure

Infants sat on their parents' lap facing a 24-in. computer monitor at a distance of approximately 60 cm from the infant. Caregivers wore sunglasses and a visor in Singapore, and were asked to look away from the screen (i.e., look down at their baby) in Spain, to prevent them from seeing the stimuli and inadvertently influence infants' behavior. Each infant was randomly assigned to one of the 24 stimulus presentation sequences. The stimulus presentation

Figure 1

Sample Trial Sequence Using Dog Images



Note. The top row represents the first half of each trial and the bottom row represents the second half of each trial. Stimuli were identical during each half of each trial, but the left–right positioning was switched from the first to the last half. Each trial (24 s) was subdivided into two 12-s parts by reversing the side of presentation for the familiar and novel referent. The familiar referent is repeated on every trial while different images are used for the novel referent on every trial.

sequences were prerecorded and presented to each infant using Microsoft PowerPoint software. The experimental session was video recorded using a camera placed under the display. Video was recorded at 30 fps. The dimensions of the eyes varied by infants, but coding was conducted on a 27-in. monitor with the child's eyes occupying about 50% of the screen.

Off-Line Coding

Trained research assistants in each testing location coded the video recordings of each experimental session frame by frame using ELAN software (ELAN, 2022). Coding consisted of identifying whether the infant looked to the right or left side of the display in each frame of a trial. The paradigm did not require infants to make a head turn but rather to launch a saccade to the left or right side of the screen. The total looking duration to the familiar referent and the novel referent on each trial was computed (the sum of looking time to each referent when it appeared on one side of the display for the first half of the trial and on the opposite side for the second half of the trial).

Data Preparation for Analyses

We first inspected attention to the task over time. Infants' looking times decreased as the task progressed (these raw looking time data are presented in Figure S1 in online supplemental material 1), with a more pronounced drop at the end of the task, likely reflecting a general decrease in task engagement over time or tiredness or both. To avoid any effects that this decrease in attention may have on infants' response patterns in the task, Trial 10 was excluded from all subsequent analyses.

Next, the proportion of looking time to the novel referent was computed for each trial, which captured infants' attention to novelty while controlling for the total looking time to the two referents spent on each trial. Trial-by-trial data were collapsed into three blocks of three trials each for statistical analyses. Data were excluded from analyses if an infant failed to contribute gaze data for at least one trial in a block, which was the case for two infants: one bilingual was 6 months old (tested in Singapore) and one bilingual was 9 months old (tested in Spain).

Results

Three types of statistical analyses were conducted. First, a linear mixed-effects model (LME) was constructed to assess the effects of task progression (nine trials grouped into three blocks equal in size), language background (monolingual and bilingual), age group (5- to 6-month-olds, 8- to 9-month-olds), and location of testing (Spain and Singapore) on infants' attention to novelty (proportion of looking time to the novel referent) (Model 1). The initial model included maximal random structure (D. J. Barr et al., 2013) but was reduced due to failure to converge until it only included random intercepts by participant. We also constructed a second model that included infants' sex as a factor (Model 1A), but model comparison based on the Akaike Information Criterion (AIC) showed that the addition of this factor did not improve model fit (Model 1 AIC = 2,468.3, Model 1A AIC = 2,497.9, $\chi^2 = 18.37$, $p = .785$), so this factor was excluded from all subsequent analyses. The models were run using the lme4 package (Bates et al., 2015) in R, and the lmerTest package (Kuznetsova et al., 2015) was used to calculate p values and conduct pairwise comparisons following significant two-way interactions. The second type of analysis consisted of one-sample t tests that compared infants' performance on each trial block to chance levels (chance = .50). Third, we conducted an exploratory Pearson correlation analysis between infants' novelty preference on each trial block and their degree of language exposure, so bilingual experience was treated as a continuous variable (percentage of exposure to infants' dominant language) collapsing across the monolingual and bilingual groups.

Monolingual and Bilingual Infants' Attention to Novelty

The main aim of this study was to investigate the effects of infants' language background on their unfolding preferences to the familiar or the novel referent as the task progressed while controlling for their general level of attention to the visual display (see online supplemental material 2 for an additional analysis of infants' total looking time during the task). For this purpose, an LME was specified with proportion of looking time to the novel object as the dependent variable. Age group, language group, trial block, location of testing, and their interaction were the independent variables. The model included random intercepts by participant (Table 2).

Table 2

Results of the Linear Mixed-Effects Model That Assessed the Effects of Age Group, Language Group, and Block on Infants' Proportion of Looking Time to the Novel Object

Factor	Num *df*	Den *df*	*F*	*p*
Age group	1	91.64	1.6378	.204
Language group	1	91.64	0.9845	.324
Block	**2**	**764.99**	**3.0508**	**.048**
Lab	1	91.64	0.7544	.387
Age Group × Language Group	1	91.64	0.0135	.908
Age Group × Block	2	764.99	1.258	.285
Language Group × Block	**2**	**764.99**	**3.2683**	**.039**
Age Group × Location	1	91.64	0.1454	.704
Language Group × Location	1	91.64	0.5893	.445
Block × Lab	2	764.99	0.1278	.880
Age Group × Language Group × Block	2	764.99	0.1644	.848
Age Group × Language Group × Location	1	91.64	0.0118	.914
Age Group × Block × Location	2	764.99	0.167	.846
Language Group × Block × Location	2	764.99	0.0276	.973
Age Group × Language Group × Block × Location	2	764.99	0.2099	.811

Note. Num *df* = numerator degrees of freedom; Den *df* = denominator degrees of freedom; statistically significant effects and interactions are marked in bold.

The LME model yielded a main effect of block and a significant language background by block interaction. As can be seen in Figure 2, infants' attention to novelty increased as the task progressed, but this effect was modulated by their bilingualism status. Specifically, bilingual infants showed a stronger novelty preference than monolinguals in Block 1, $\beta = -0.286$, $SE = 0.126$, $t = -2.264$, $p = .024$, CI [−0.534, −0.038], but the two groups did not differ significantly in Block 2, $\beta = -0.094$, $SE = 0.126$, $t = -0.740$, $p = .460$, CI [−0.342, 0.155], or Block 3, $\beta = 0.117$, $SE = 0.127$, $t = 0.919$, $p = .359$, CI [−0.133, 0.367].

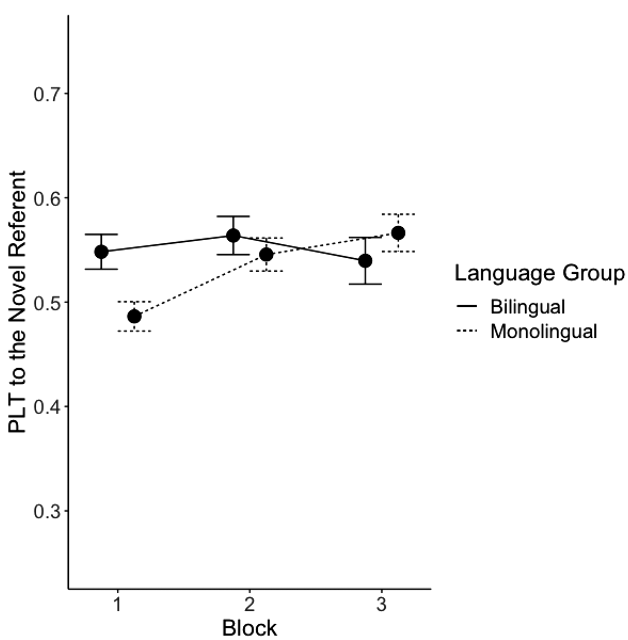
This pattern of bilingual infants orienting more readily to novelty observed in the model was confirmed by one-sample t tests that compared monolingual and bilingual infants' novelty preference to the level of chance (chance = .50). The resulting p values were adjusted via Bonferroni correction for multiple comparisons (six t tests, $p = .008$). Given that no effects of age group were observed in previous models, data for the 5- to 6-month-olds and 8- to 9-month-olds were collapsed for these analyses. As seen in Table 3, in the monolingual group, a novelty preference emerged in Block 3, with no significant preferences in Blocks 1 or 2. In the bilingual group, however, the pattern was reversed. Infants already showed a marginal preference in Block 1, which became significant in Block 2, but no preference for either stimulus in the final block of the task.

Infants' Individual Language Exposure Patterns and Attention to Novelty

All analyses reported so far treated infants' bilingualism status as a categorical variable, thus failing to capture potential relations between individual language exposure patterns and attention to novelty in this task. For this purpose, we conducted a correlation analysis with infants' novelty preference scores in each trial block and percentage of exposure to the dominant language (Figure 3). In line with our between-group analyses, two significant correlations were observed: a negative correlation between infants' dominant language exposure and novelty preference in Block 1, and a positive correlation between dominant language exposure and novelty preference in Block 3. Next, we repeated this analysis only for the subset of bilingual infants, and observed an identical pattern of results: a negative correlation between novelty preference and bilingual infants' dominant language exposure in Block 1, $r = -.289$, $p = .052$, and a positive correlation between novelty preference and bilingual infants' dominant language exposure in Block 3, $r = .331$, $p = .025$ (these correlations are plotted in Figure S3 in online supplemental material 3). Thus, in the full sample and in the subset of bilingual infants, we observed that infants who were more balanced bilinguals (i.e., with dominant language exposure closer to 50%) showed a stronger novelty preference in the first trial block of the task, but a weaker novelty preference in the final block.

Figure 2

Proportion of Looking Time to the Novel Referent for Monolingual and Bilingual Infants (Data Collapsed Across Age Groups) in Blocks 1, 2, and 3



Note. PLT = proportion of looking time. Error bars indicate standard error of the mean.

Discussion

The goal of the present study was to determine whether bilingualism was associated with variation in infants' attentional preferences to novel and familiar stimuli. In particular, we sought to investigate whether a longstanding postulate in infant research—that infants gradually orient toward novelty with increased exposure to a familiar stimulus—is dependent on language experience. Our study yielded three main findings. First, in a series of three blocks of trials, we found that monolingual infants and bilingual infants differed in their visual preferences during the first block of trials. The pattern of performance obtained with monolingual infants replicates Fantz's (1964) study with infants of the same age group as our samples. However, the earlier emergence of an orientation toward novel stimuli in bilingual infants deviated from Fantz's findings, suggesting that the preference for novel stimuli emerges more rapidly in bilingual infants.

Second, as infants acquired more experience with both familiar and novel stimuli, bilingual infants demonstrated a continued novelty preference for the first two blocks of trials. After this, they demonstrated a null preference. In contrast, monolingual infants moved from a null preference in the first two blocks to a novelty preference in the third block. Therefore, for each block, both groups showed opposing patterns of preference. The pattern demonstrated by monolingual infants over the course of the session resembled attentional patterns documented by Fantz in same-aged infants (a null preference followed by a progression toward the novel stimulus). Bilingual infants represented a different pattern, progressing to a novelty preference over the first two blocks followed by a null preference in the final block.

Third, the relationship between language input and novelty preference varied by block. In the first block, infants with more second language exposure fixated the novel stimulus in greater measure. There were no effects of language exposure in the medial block. In the last block, infants with more second language exposure fixated to the novel stimulus to a lesser extent. Finally, there were no effects of age group and country of testing (which covaried with languages heard).

Table 3

*Descriptive Statistics (*M = *Mean,* SD = *Standard Deviation) and Results of* t*-Test Analyses Comparing Monolingual and Bilingual Infants' Performance to Chance (.50) in Trial Blocks 1, 2, and 3*

Block	Monolingual ($df = 52$)	Bilingual ($df = 45$)
Block 1	$M = .486$, $SD = .113$ $t = -0.877$, $p = .385$, Cohen's $d = -0.120$	$M = .548$, $SD = .122$ $t = 2.662$, $p = .011$, Cohen's $d = .392$
Block 2	$M = .547$, $SD = .145$ $t = 2.341$, $p = .023$, Cohen's $d = .322$	$M = .564$, $SD = .107$ $t = 4.084$, $p = .001$, Cohen's $d = .602$
Block 3	$M = .568$, $SD = .136$ $t = 3.612$, $p = .001$, Cohen's $d = .496$	$M = .540$, $SD = .147$ $t = 1.846$, $p = .071$, Cohen's $d = .272$

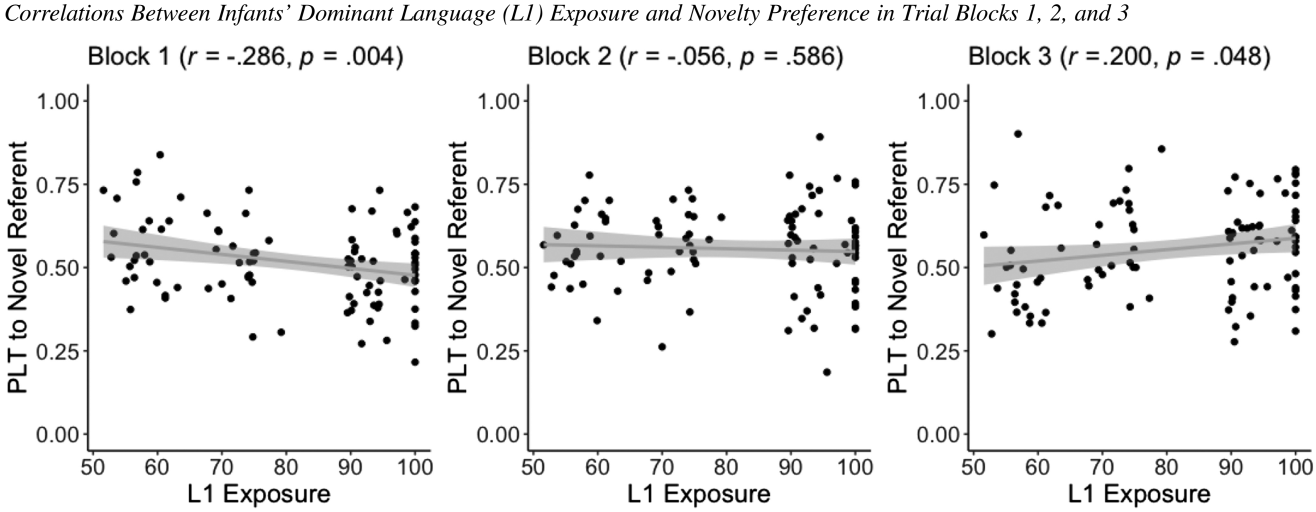
Theoretical Implications

The present set of findings suggests that a widely documented attentional shift in infants away from a familiar stimulus over time does not generalize to bilingual infants. The findings provide empirical support for recent theoretical perspectives (D'Souza & D'Souza, 2021; Singh, 2021) suggesting that bilingual experience may shift infants' attentional focus away from familiar stimuli and toward novel stimuli and may modify how infants explore their environments. This observation raises the question of why bilingual infants demonstrate a greater orientation toward novelty. We propose two reasons for why such an orientation may be adaptive for bilingual environments. First, bilingual infants are exposed to linguistic systems that may differ—and even conflict—at one or more levels of linguistic description. Such contrast or conflict may introduce less predictability and greater uncertainty for bilingual learners (see Gullifer & Titone, 2021). For example, when learning Mandarin Chinese and English, learners have to attribute different properties to the same linguistic units in each language. Chinese, being a tone language, requires attention to pitch movements that signify both lexical (i.e., word meaning) and intonational (e.g., emotional) meaning. In contrast, English requires attention to pitch movements that distinguish only intonational contrast. The presence of phonological conflict appears to attenuate tone discrimination in Mandarin–English bilinguals (Singh et al., 2018). Similarly, Spanish and Catalan differ in their vowel and consonant inventories. There are particular vowels that are contrastive in Catalan, but surface noncontrastively in Spanish. Spanish–Catalan learners, therefore, have to maintain a more complex phonetic space for these vowel contrasts due to the conflict across languages. Similar to Mandarin–English bilinguals, Spanish–Catalan bilinguals demonstrate an attenuation in perception of vowels that conflict across languages (Bosch & Sebastián-Gallés, 2003).

Bilingual environments also contain heightened variability, which may create greater uncertainty (Byers-Heinlein & Fennell, 2014). Heightened variability in bilingual environments takes various forms: Bilingual infants encounter a greater range of sounds, words, grammatical constructions, and pragmatic conventions compared with monolingual peers. To become linguistically proficient in two languages, at each level of linguistic description, properties of languages must be associated with a single language so that learners use each language selectively as warranted by the context. However, to go back and forth between two languages, learners must also associate properties of one language with the other language. This process of separation and association of both languages requires an additional layer of organization of incoming speech and language, making the induction of underlying structure more complex. This requirement may lead learners to explore their environment more broadly and remain more flexible in early stages of development.

Figure 3

Correlations Between Infants' Dominant Language (L1) Exposure and Novelty Preference in Trial Blocks 1, 2, and 3



Note. PLT = proportion of looking time; L1 = first language. Shaded area represents standard error of the mean.

Although the aforementioned studies in speech perception have focused on auditory experience, language experience is a multimodal event that not only involves auditory experience, but also modifies the visual environment. Past studies have demonstrated that more so than monolingual learners, bilingual learners are more dependent on visual information in language input (Chauvin & Phillips, 2022; Sebastián-Gallés et al., 2012), raising the possibility that visual information may be harnessed to a greater extent in bilingual learners. As a result, we would expect effects of bilingualism on perception and learning to span the different modalities within which language presents itself. Empirical evidence is aligned with this expectation: Effects of bilingualism on perceptual flexibility are observed in the auditory domain (Petitto et al., 2012; Singh, 2018; Singh & Tan, 2021; Singh et al., 2017) and in the visual domain (R. Barr et al., 2020; Brito & Barr, 2012, 2014; D'Souza et al., 2020, 2021; Singh et al., 2023). The latter set of studies demonstrates a range of areas of visual perception where bilingual flexibility is more pronounced, including objects, action sequences, motion events, and visual patterns.

Within an environment of heightened uncertainty, it may be more adaptive to distribute attention within the environment in order to discern underlying structure and to remain attuned to subtle changes in auditory and visual modalities. Bilingual infants may therefore be driven to sample more broadly on account of greater indeterminacy and ambiguity in their linguistic environment (D'Souza & D'Souza, 2021; Singh, 2021). Broader sampling could account for greater sensitivity to stimulus change in bilingual infants. Increased sensitivity to perceptual contrast may arise from a combination of greater attentional switching (D'Souza et al., 2020) and increased exploration of novel stimuli, as reported in the current study.

Past studies have proposed alternative accounts, suggesting that bilingual learners adapt to the complexity of processing dual language input by developing an increased capacity for cognitive control (e.g., Abutalebi & Green, 2016). Although the robustness of evidence for increased cognitive control in bilingual infants remains in question (e.g., Blanco-Elorrieta & Pylkkänen, 2018), it is possible that bilingual experience shifts more basic aspects of attention. This line of argument relies less on the competitive pressures introduced by two languages that have been central to claims of cognitive control advantages on bilingual learners (Bialystok, 2007). Instead, it relies more on adaptation and optimization to environmental unpredictability and uncertainty. Differences observed between monolingual and bilingual infants are analogous to the explore-exploit tradeoff in how observers adapt to environmental demands (Stephens & Krebs, 1984; see also Gopnik, 2020), where a useful adaptation to uncertainty may be to attend broadly within the environment while in the process of determining underlying structure. This argument further suggests that effects of bilingualism on attentional sampling are not specific effects of language exposure, but generalized effects of environmental diversity and complexity. Along these lines, such effects may also be evident within groups that encounter greater uncertainty along other social–environmental dimensions (e.g., infants raised in multiracial or multidialectical environments).

Our findings are broadly consistent with a recent study investigating attentional orienting to predictable and unpredictable event sequences in monolingual and bilingual infants (Arredondo, Aslin, & Werker, 2022). In this study, at 6 months, bilingual infants and monolingual infants showed increased neural activity in frontal brain regions for predictable sequences, as expected based on prior research. However, at 10 months, monolingual infants showed a similar pattern, favoring predictable sequences, but bilingual infants showed increased activation for unpredictable sequences, a more costly form of neurocognitive processing (Arredondo, Aslin, & Werker, 2022). In a longitudinal follow-up, the same authors demonstrated that bilingual infants showed gains in processing these attentionally demanding stimuli as they matured, pointing to an enduring bilingual orientation toward unpredictable stimuli (Arredondo, Aslin, Zhang, & Werker, 2022). The authors suggest that this orientation stems from an increased tendency and ability to shift attention from information that is predictable and therefore, familiar, to information that is novel. Arredondo, Aslin, Zhang, and Werker (2022) also showed that gains in processing unpredictable information were associated with language switching within the parents of bilingual infants. Although the causal direction of this relationship is difficult to pinpoint, it suggests that the demands of processing bilingual input may be associated with broader exploration within the visual environment, albeit at some computational expense.

A second possibility is that bilingual experience is associated with increases in processing efficiency. This suggestion derives from the observation that bilingual infants receive less single-language input than monolingual infants, yet they have to attain native proficiency in each language to become bilingual. In some sense, infants, therefore, have to "get by on less." The learning demands in this situation may increase efficiency of processing, which in turn may lead to a faster transition to novel stimuli. This argument is grounded in theoretical frameworks that suggest that infants transition from familiarity to novelty preferences when they have developed greater processing efficiency (i.e., when a task becomes easier or a stimulus becomes less complex to process) (Rose et al., 2004). If bilingual exposure contributes to increased processing efficiency, then the familiarity-to-novelty transition may be accelerated (rather than entirely preempted). This possibility is consistent with a disengagement account (e.g., D'Souza et al., 2020; Kalashnikova et al., 2021) suggesting that visual disengagement from familiar stimuli occurs more rapidly in bilingual infants. Unlike the previous account, this account is less centered around environmental complexity and instead, focused on reduced environmental input. It could be investigated by sampling younger bilingual infants, who may be expected to begin with a null preference or a familiarity preference on account of more immature processing abilities or by using more complex or abstract stimuli that may be more effortful to process.

Our study raises the question of longer-term outcomes of an early novelty orientation. Past studies have linked novelty preferences to positive cognitive outcomes (Fagan, 1984; Thompson et al., 1991). In a recent study, D'Souza and Dakhch (2022) reported an increased ability in bilingual adults to solve novel reasoning problems, an effect that was greater in early bilinguals versus late bilinguals and greater in bilinguals versus monolinguals. Effects of language experience withstood variation in socioeconomic status. It is possible that environmental complexity increases perceptual and cognitive openness in a manner that allows learners to succeed at higher order problem-solving in novel situations. This possibility remains speculative and warrants longitudinal investigation, but it points to the prospect that there may be longer-term outcomes in cognitive processing on account of early bilingual experience.

Methodological Implications

Our findings have implications for methodological approaches to infant cognition, suggesting that the core processes being tapped in the dominant paradigms used to track infant perception, learning, and memory may be vulnerable to effects of environmental experience. Measurement of visual attention serves as the primary vehicle by which researchers have investigated the organization of the infant mind (Csibra et al., 2016). Visual attention is typically operationalized by looking time, which is commonly extracted from methodologies such as visual habituation, head-turn preference, and preferential looking. The use of infant looking to reveal latent cognitive processes has been a longstanding practice in developmental psychology originating with Fantz (1964). Over the past few decades, looking time measures have guided both empirical studies and theory building in a wide array of infant research such as moral development (Sloane et al., 2012), language acquisition (Swingley & Aslin, 2000), categorization (Mareschal & Quinn, 2001), executive function development (Cuevas & Bell, 2013), sensitivity to visual contrast (Rose et al., 2004), perceptual organization (Bhatt & Quinn, 2011), understanding of causality (Leslie, 1982), and sensitivity to number (Xu & Spelke, 2000). However, prevailing models of infant visual attention have advanced generalized interpretations of infant looking time (e.g., Aslin, 2007; Colombo, 2001; Hunter & Ames, 1988), reflecting a broader predisposition toward presumptions of homogeneity in underlying psychological processes (DeJesus et al., 2019). Studies such as the present investigation suggest even behaviors believed to be fundamental and generalizable may be contextually variable in ways that have not been reported. More specifically, the current findings suggest that bilingual exposure should be reported and its effects modeled even in studies that do not directly measure linguistic responses (see Byers-Heinlein et al., 2019 for a discussion of this issue).

Constraints on Generalizability

Although we sampled different groups of monolingual and bilingual infants, both monolingual and bilingual infants are heterogenous populations. Our findings draw from two distinct geographical regions. However, it remains an open question whether bilingual populations, in general, demonstrate an orientation toward novelty. Increasing participant diversity in further studies would help to answer this question. In addition, as stated, it is not clear that an increased novelty orientation is specific to bilingual populations or whether it extends to other populations who face increased environmental complexity. Further studies are needed to draw more firm conclusions on these issues.

Conclusion

The present study suggests that bilingual exposure may be associated with variation in infants' looking preferences, with a greater orientation toward visual novelty in bilingual infants. We suggest that a novelty orientation in bilingual infants may arise from a broad sampling of environmental input. Distributing attention broadly may be a useful adaptation for navigating more complex systems, where uncertainty is elevated. Alternatively, bilingual infants may process information more rapidly, accelerating the transition from familiar to novel stimuli. Regardless, the findings reported here demonstrate that fundamental measures of infant processing vary based on language experience.

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