Cognitive gains in 7-month-old bilingual infants

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Children exposed to bilingual input typically learn 2 languages without obvious difficulties. However, it is unclear how preverbal infants cope with the inconsistent input and how bilingualism affects early development. In 3 eye-tracking studies we show that 7-month-old infants, raised with 2 languages from birth, display improved cognitive control abilities compared with matched monolinguals. Whereas both monolinguals and bilinguals learned to respond to a speech or visual cue to anticipate a reward on one side of a screen, only bilinguals succeeded in redirecting their anticipatory looks when the cue began signaling the reward on the opposite side. Bilingual infants rapidly suppressed their looks to the first location and learned the new response. These findings show that processing representations from 2 languages leads to a domain-general enhancement of the cognitive control system well before the onset of speech.

cognitive development | early bilingualism | executive functions | eye-tracking | infant cognition

"When I was talking to my paternal grandmother I had to speak in a manner that I later discovered was called English, and when I was talking to my mother or her parents I had to talk a language that afterward turned out to be Spanish" notes J. L. Borges (1). In contemporary societies many children grow up in bilingual families and are faced with similar situations. Just like the young J. L. Borges they successfully learn to cope with different languages. However, a single language milieu is still the standard model for investigating language acquisition even though a great proportion of children are raised with more than 1 language (2). Whereas infants who have to acquire 2 languages simultaneously face an important challenge, they pass language production milestones at an age similar to monolinguals (3), and display minor differences in language processing (4, 5). The present study investigates the mechanisms that bilingual infants might employ to deal efficiently with a linguistic signal coming from 2 languages.

Previous studies have shown that infants process various aspects of the languages they are exposed to from very early on. Indeed, neonates can discriminate utterances from 2 languages of different rhythmic classes (6–8). Two- to four-month-olds learn to distinguish languages belonging to the same rhythmic class (4, 9). Later on, in the second half of their first year, infants show exposure-dependent changes in phonetic discrimination (10, 11). These studies suggest that well before infants start speaking they have already acquired crucial properties of their maternal language.

How do bilingually raised infants, who lack the homogeneous input of monolinguals, cope with their linguistic environment? We suggest that preverbal bilinguals using their ability to differentiate utterances from 2 languages already build separate representations for each of the languages. Earlier proposals have suggested that during speech production bilinguals must continuously control their 2 languages to access the linguistic representations of the target language while avoiding interference from the nontarget language (12). Thus, to efficiently manage 2 languages bilingual speakers must employ their cognitive control abilities. In fact, cognitive control or executive functions (EF) refer to mechanisms involved in conflict monitoring, planning, attentional control, and the suppression (inhibition) of habitual responses (13, 14). Previous research has shown that the habitual use of 2 languages leads to improved cognitive control in young and older adults and in preschool and school-aged children (15–18). This improvement is generally attributed to the need of bilinguals to inhibit one language while switching to the other language in production (12, 19).

To understand the effects of bilingualism on EF, we investigated whether preverbal monolingual and bilingual infants differ in their ability to master tasks that engage EF. Although EF are immature in infancy (20), circumstances that require the extensive use of such mechanisms may accelerate their development. Early bilingualism may be one of these circumstances. We conjecture that perceiving and processing 2 languages may be sufficient to enhance EF before infants actually learn to speak.

Learning the properties of their native languages requires that bilingual infants build representations appropriate for each of their languages from a mixed linguistic input. We assume that to selectively construct and access their 2 languages bilingual infants have to use their monitoring and control abilities. If so, they may gain practice in using such abilities well before they start producing utterances. Our work explores whether these mechanisms are crucial to the simultaneous acquisition of 2 languages and, thus, whether a continuous bilingual exposure enhances the development of EF in preverbal infants.

To evaluate the impact of bilingualism on early cognitive development, we compared the performance of monolingual and bilingual preverbal 7-month-old infants on tasks that require the use of EF. The bilingual infants participating in our studies were "crib bilinguals," that is, infants exposed to 2 languages from birth onwards. If the exposure to 2 languages enhances EF, bilingual infants should outperform monolinguals on EF tasks but not on tasks that do not involve EF. In our studies, infants first learn a response triggered by a cue. After this initial phase they have to learn a second, conflicting response to the cue. Although learning the initial response should not depend on EF abilities, learning the second, conflicting response requires inhibiting the first response and may thus involve EF. Indeed, previous research has found that 7-month-old infants have difficulty overcoming earlier-learned behaviors due to poorly developed inhibitory control (21, 22). However, here we propose that 7-month-old bilingual infants might already show an advantage in EF abilities. Hence, whereas both monolinguals and bilinguals should succeed in learning the first response, bilinguals should outperform monolinguals in learning the second response where they need to employ EF.

Results

Experiment 1. In experiment 1 we studied 20 monolingual 7-month-old infants (mean age, 7.22) and 20 bilingual 7-month-old infants (mean age, 7.20) on a switch task involving speech-like cues. Monolingual and bilingual infants were matched for

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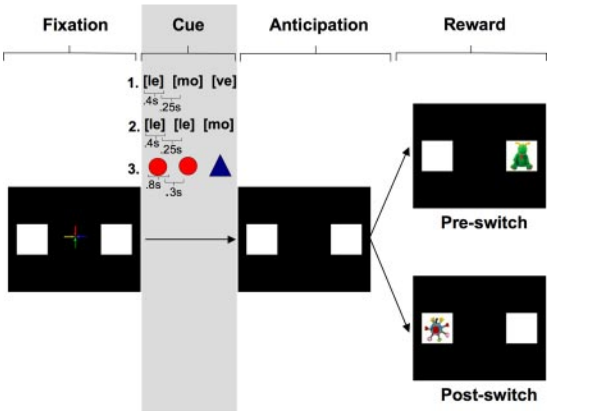

Fig. 1. Trial structure of the 3 experiments. Trials started with a fixation display showing a central visual attractor (minimum duration, 0.5 s). In experiments 1 and 2 participants listened to speech cues (1.7 s). In experiment 3, participants saw visual cues (3 s). In experiment 1 the speech cues consisted of nonsense words containing 3 different syllables. In experiment 2, the speech cues had a certain repetition structure in the preswitch phase, i.e., AAB, as in le-le-mo, and a different repetition structure in the postswitch phase, i.e., ABB, as in le-mo-mo. After the offset of the cue, the anticipatory period (duration, 1 s) began. At the end of the anticipatory period a visual reward (2 s) appeared on one side of the screen. The reward was always displayed on the same side of the screen during the preswitch phase (9 trials) and on the other side during the postswitch phase (9 trials).

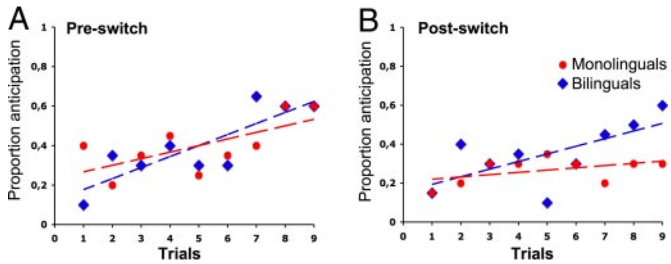

Fig. 2. Results of experiment 1. Symbols represent the proportion of infants with correct anticipatory looks. Red dots represent population averages for monolinguals, and blue diamonds represent averages for bilinguals. Regression lines are shown for both groups. (*A*) In the preswitch phase both groups of participants increased anticipatory looks to the correct side after the speech cue from the first to the last trials. (*B*) In the postswitch phase only bilinguals learned to anticipate correctly over the trials.

age, gender, and their parents' socioeconomic status. Infants were considered bilingual if they had parents with different mother tongues addressing them consistently in their respective native languages and if they had daily exposure to both languages.

Participants were tested in a preswitch phase (9 trials) followed by a postswitch phase (9 trials; see Fig. 1). In the preswitch trials, infants were presented with a speech cue followed by a visual reward. Cues were 9 trisyllabic, meaningless words (hereafter just "words") and the visual reward (a looming puppet) always appeared on the same side of the screen in a white square. Two white squares were continuously displayed on the screen; half of the infants received the reward on the left side of the screen and the remaining infants on the right side. Infants had to learn that the cue predicted the appearance of the reward in a specific location. In the postswitch trials, infants were exposed to different trisyllabic words and the reward was presented on the opposite side of the screen. Thus, during the postswitch, infants had to learn to redirect their gaze from the previously valid side toward the opposite side of the screen. The rewards (3 different puppets) were randomly paired with the cues. The sides where the puppets first appeared were counterbalanced across infants. The stimuli were presented via an Apple Dual G5 computer running the PsyScope X program (avialable at http://psy.ck.sissa.it).

We measured learning by recording infants' anticipatory looks with a Tobii 1750 Eye Tracker (23). An anticipatory look was defined as an eye movement performed to one side of the screen within 1 s after the end of the word and before the appearance of the visual reward. If infants learn that the cue predicts the location of the visual reward, then, over the trials, they should increase their anticipatory looks to the region where they expected the reward to appear.

Assuming that the only systematic difference between the 2 groups is their linguistic background, we predicted that in the preswitch phase, in which infants had to learn the first response, the 2 groups would perform similarly because no EF are required. In the postswitch phase, however, to learn the new response infants had to disregard their first response. If bilingual infants develop better EF, they should disengage faster than monolinguals from the learned response. Thus, in the postswitch phase, bilinguals should be better than monolinguals at inhibiting their first response and learning a new one.

Fig. 2 shows the proportion of anticipatory looks to the side where the visual reward appeared in the 2 phases. For the comparisons we grouped the trials in blocks of 3 (first/middle/last) in the 2 phases, respectively. Both monolinguals and bilinguals showed fast learning during the preswitch phase (see Fig. 2*A*), as revealed by a main effect of Block [$F_{2,76} = 16.41$, $P < 0.0001$, no effect of Group (monolingual/bilingual) or interaction]. Thus, both groups increased their correct anticipatory looks alike during the trials of the preswitch phase (Scheffé post hoc first vs. last Block: monolinguals, $P = 0.001$; bilinguals, $P = 0.0001$). However, only bilinguals displayed an increase in correct anticipatory looks during the postswitch phase [main effect of Block: bilinguals, $F_{2,38} = 6.21$, $P = 0.004$; monolinguals, P value not significant (ns)]. Accordingly, in contrast to the preswitch phase, Block interacted with Group ($F_{2,76} = 4.78$, $P < 0.01$) (see Fig. 2*B*). Post hoc tests (Scheffé) confirmed that only bilinguals increased their anticipations to the new location (first vs. last Block, $P = 0.01$), displaying more correct looks on the last Block than monolinguals ($P = 0.007$), whereas the groups did not differ in total anticipations (correct and incorrect). By the end of the postswitch phase, bilinguals also decreased anticipatory looks to the side that had been valid during the previous phase, whereas monolinguals did not (perseveration decrease: bilinguals, $F_{2,38} = 4.3$, $P = 0.02$; monolinguals, P value ns).

As mentioned above, the finding that monolinguals have difficulty overcoming a well-learned response fits well with previous results showing that 7-month-old infants display perseveration and difficulty inhibiting previously rewarded responses due to their immature EF (24). In our study, however, bilinguals significantly decreased their perseverative responses and increased anticipations to the new location, which suggests that a multilingual environment improves aspects of EF even in preverbal infants.

Experiment 2. In experiment 2 we investigated whether monolinguals would also learn the new response when given an index to signal the switch. Thus, the structure of the speech cues differed in the preswitch and the postswitch phase. All words in the preswitch phase had the same structure (e.g., AAB, initial repeated syllables), and all words in the postswitch had a different structure (e.g., ABB, final repeated syllables). We used these structures because 7-month-old infants and even newborns discriminate these regularities (25, 26).

Experiment 2 employed the same method and procedure as experiment 1, except that the structure of the cues differed in the 2 phases of the experiment. We tested 2 new groups of 7-month-old infants [20 monolinguals (mean age, 7.19) and 20 bilinguals

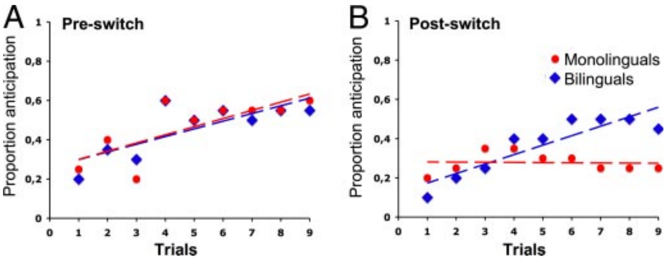

Fig. 3. Results of experiment 2. Symbols represent the proportion of infants with correct anticipatory looks. Red dots represent population averages for monolinguals, and blue diamonds represent averages for bilinguals. Regression lines are shown for both groups. (*A*) In the preswitch phase both groups of participants increased anticipatory looks to the correct side after the structured speech cue from the first to the last trials. (*B*) In the postswitch phase only bilinguals learned to anticipate correctly over the trials.

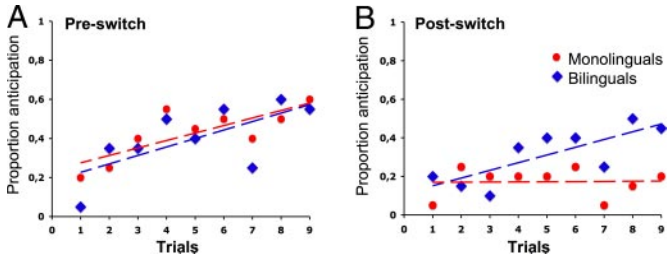

Fig. 4. Results of experiment 3. Symbols represent the proportion of infants with correct anticipatory looks. Red dots represent population averages of monolingual infants, and blue diamonds represent averages for bilinguals. Regression lines are shown for both groups. (*A*) Both groups increased anticipatory looks to the correct side after the visual cue during the preswitch phase. (*B*) As in experiment 1 only bilinguals showed an increase in correct anticipations during the postswitch phase.

(mean age, 7.16)]. The recruitment and testing of infants was as described in experiment 1.

Fig. 3 shows the proportion of anticipatory looks to the side where the visual reward appeared. Both monolinguals and bilinguals showed fast learning during the preswitch phase (see Fig. 3*A*), as revealed by a main effect of Block ($F_{2,76}$ = 13.83, $P <$ 0.0001, no effect of Group or interaction). Thus, both groups increased correct anticipatory looks in a similar manner (Scheffé post hoc first vs. last Block: monolinguals, P = 0.0005; bilinguals, P = 0.01). However, similarly to experiment 1, only bilinguals displayed an increase in correct anticipatory looks during the postswitch phase (main effect of Block: bilinguals, $F_{2,38}$ = 9.12, P = 0.006; monolinguals, P value ns). Accordingly, in contrast to the preswitch phase, Block interacted with Group ($F_{2,76}$ = 4.02, P = 0.02) (see Fig. 3*B*). Post hoc tests (Scheffé) confirmed that only bilinguals increased their anticipations to the new location (first vs. last Block, P = 0.001), displaying more correct looks on the last Block than monolinguals (P = 0.01), whereas the groups did not differ in total anticipations (correct and incorrect). By the end of the postswitch phase, bilinguals decreased anticipatory looks to the side that had been valid during the previous phase, whereas monolinguals did not (perseveration decrease: bilinguals, $F_{2,38}$ = 6.4, P = 0.004; monolinguals, P value ns). When comparing experiments 1 and 2, experiment and Block interaction showed that both groups learned faster in the preswitch phase of experiment 2 [bilinguals, $F_{2,76}$ = 3.9, P = 0.02 (Scheffé post hoc middle Block experiment 1 vs. middle Block experiment 2, P = 0.02); monolinguals, $F_{2,76}$ = 3.58, P = 0.03 (Scheffé post hoc middle Block experiment 1 vs. middle Block experiment 2, P = 0.009)]. However, only bilinguals showed faster learning in the postswitch phase (experiment and Block interaction bilinguals, $F_{2,76}$ = 3.95, P = 0.02; Scheffé post hoc middle Block experiment 1 vs. middle Block experiment 2, P = 0.04; monolinguals, P value ns.). Thus, although infants may be sensitive to the structure of the cues, monolingual 7-month-olds, unlike bilinguals, do not learn the new response in the postswitch phase, even when the switch is signaled by differently structured cues. These results support the conclusions of experiment 1, confirming the hypothesis that bilinguals display an advantage in EF development preverbally.

Experiment 3. Is the EF enhancement observed in bilinguals restricted to the modality in which they might employ EF in the service of language acquisition, namely, the auditory modality? Alternatively, these improvements may arise even when the modality of the test is unrelated to that of learning. To investigate this question, we explored whether the bilingual EF enhancement is present only when infants are responding to speech cues, or whether it can also be observed when they are responding to cues in the visual modality.

Experiment 3 employs the same method and procedure as experiment 2. Infants were exposed to cues that predicted rewards in specific locations. However, the cues now were triplets of sequentially presented visual figures instead of trisyllabic words (see Fig. 1). In this study we tested 2 new groups of 7-month-old infants [20 monolinguals (mean age, 7.17) and 20 bilinguals (mean age, 7.17)]. The recruitment and testing of infants was as described in experiment 2. If bilingual infants outperform their monolingual peers in the postswitch phase despite the use of visual rather than speech cues, this would suggest a general EF enhancement in bilingual 7-month-old infants.

In experiment 3 both groups increased their correct anticipatory looks during the trials of the preswitch phase (see Fig. 4*A*), as revealed by a main effect of Block ($F_{2,76}$ = 8.97, P = 0.0003, no effect of Group or interaction; Scheffé post hoc first vs. last Block monolinguals, P = 0.04; bilinguals, P = 0.02). However, only bilinguals increased their correct anticipatory responses to the novel location during the postswitch (main effect of Block: bilinguals, $F_{2,38}$ = 7.57, P = 0.001; monolinguals, P value ns). As in experiments 1 and 2, Block interacted with Group only in the postswitch phase ($F_{2,76}$ = 3.88, P = 0.02; Scheffé post hoc first vs. last Block: bilinguals, P = 0.004; monolinguals, P value ns) (see Fig. 4*B*). Bilinguals had more correct looks on the last Block of the postswitch phase than monolinguals (Scheffé, P = 0.002), whereas the groups did not differ in total number of anticipations. In contrast to monolinguals, bilinguals successfully redirected their anticipatory looks to the opposite side of the screen, showing their ability to overcome a previously learned but no longer valid response (perseveration decrease: bilinguals, $F_{2,38}$ = 5.74, P = 0.006; monolinguals, P value ns).

Discussion

Whereas both monolingual and bilingual infants learned equally well that a speech or visual cue predicted the position of a visual reward in the preswitch phase of each experiment, we observed a major behavioral difference between the 2 groups in the respective postswitch phases. Bilinguals readily suppressed the previously learned response and updated their predictions according to the changing requirements of the task, whereas monolinguals did not learn the new response during the trials of the postswitch phase. The bilinguals' enhanced performance cannot be attributed to a systematic difference in general information processing abilities because the performance of the 2 groups was comparable during the preswitch phase of the 3 experiments.

Taken together, these results suggest that perceiving and processing utterances from 2 languages during the first months of life improves domain-general components of EF well before language production begins. Hence, although suppression of one language when speaking the other is well attested, it is not necessarily required for EF improvement. Rather, just processing 2 languages and having to deal with the representations of each of them is sufficient for enhancing executive control. Their well-developed EF abilities may help bilinguals to successfully monitor and keep separate the linguistic representations of the 2 languages, thus allowing them to efficiently acquire each language.

These results also shed light on previous debates about the positive or negative consequences of exposure to a bilingual input (27, 28). Our data reveal an advantage in executive control for crib bilingual infants, regardless of whether they were tested with visual or auditory cues. These results point to precocious cognitive benefits resulting from early exposure to a multilingual environment. How much the EF enhancement in bilinguals depends on the context of language acquisition (crib or school bilingualism) or on the similarity of languages (same or different language classes) are questions that remain to be answered with future research. Although earlier studies focused on bilingual preschool or school-aged children, who typically speak one language at home and another one at school (15), crib bilinguals are exposed to 2 languages from birth and have to acquire both languages simultaneously in their home settings. Potentially, learning 2 languages in the same setting might require crib bilinguals to rely more on EF than those infants who learn one language at home and the other in a different environment.

Experience-dependent enhancements as the ones described here might be of interest for research on neural plasticity with potential consequences for education and remediation. Caretakers and educators are often faced with the question of how bilingual exposure affects early development, because more and more infants are born into bilingual milieus across the world. Our studies also offer a response to such concerns by showing that crib bilingualism promotes the development of important cognitive control functions already at a preverbal age.

Materials and Methods

Experiment 1. ***Participants.*** Forty infants were retained for the analysis [20 Italian monolinguals (9 girls) and 20 bilinguals (9 girls); age range, 7 months 1 day to 7 months 30 days]. Participants were recruited in Trieste, Italy and surrounding areas. All participants were healthy full-term infants. Fourteen bilinguals heard Italian and Slovenian, 2 heard Italian and Spanish, 2 heard Italian and English, 1 heard Italian and Arabic, and 1 heard Italian and Danish. Twelve infants were excluded (6 monolinguals and 6 bilinguals) due to fussiness or experimental error. Parents of the infants participating in the 3 experiments gave informed consent before the experiments. The study design was approved by the Ethics Committee of Scuola Internazionale Superiore di Studi Avanzati, where the experiments were conducted.

Stimuli. The auditory cues were trisyllabic words. We constructed 18 nonsense words from 6 syllables (le, zo, ni, mo, ri, and ve). Each phoneme was 200 ms long with a monotonous pitch of 200 Hz. Syllables were separated by 250-ms pauses and synthesized with MBROLA (29) using package DE7 (soft). The visual rewards were 3 pictures of colored puppets that appeared inside one of the 2 white squares on the left or right side of the screen. The puppets loomed from 4 to 7 cm (visual angle from the infants' view was 9.14–15.9°) for 2 s. The squares had a side-length of 8 cm (18.18°), positioned at a distance of 13.5 cm (30.2°).

Procedure. The study consisted of 9 preswitch and 9 postswitch trials. Trials in the pre- and postswitch phases started with a display of 2 white squares, one on either side of the screen, and a central visual attractor. A word was presented while the visual attractor was displayed. When the word ended, only the 2 white squares were visible for 1 s. Then a looming puppet accompanied by a tinkling sound appeared consistently on one side of the screen in the preswitch phase and on the other side of the screen in the postswitch phase. The initial side was counterbalanced across participants. The postswitch and the preswitch phases were identical with the exception of the visual reward, which appeared on the opposite side during the 2 phases.

Scoring. The screen was divided into 3 equal parts: left, middle, and right. We coded infants' anticipatory looks to the left or right side of the screen that occurred during the 1-s time window starting 150 ms after the end of the word and ending 150 ms after the appearance of the reward. These criteria were based on previous studies (30–32). Trials in which the infant performed an anticipatory look to the side where the puppet would appear were coded as correct. If the infant did not look to the correct side during the anticipatory period the trial was coded as incorrect. When infants looked both to the correct and incorrect sides during the anticipatory period of the same trial, the side of the longer look was coded. Taking the first look yields practically identical data, given that in 94.8% of the trials infants looked to only one side. As an additional analysis, we also coded perseverative looks in the postswitch phase, that is, anticipatory looks to the location that had been valid previously.

Experiment 2. ***Participants.*** Forty infants were included in the analysis [20 Italian monolinguals (11 girls) and 20 bilinguals (11 girls); age range, 7 months 3 days to 7 months 30 days]. Participants were recruited in Trieste, Italy and surrounding areas. All participants were healthy full-term infants. Fifteen bilinguals heard Italian and Slovenian, 1 heard Italian and Spanish, 2 heard Italian and English, and 2 heard Italian and French. Fifteen infants were excluded (8 monolinguals and 7 bilinguals) due to fussiness or experimental error.

Stimuli. The auditory cues were trisyllabic words, as in experiment 1. However, during one of the phases, the words conformed to an AAB structure, with initial repeated syllables as in le-le-mo, and during the other phase they conformed to an ABB structure, with final repeated syllables as in le-mo-mo. We constructed 9 AAB and 9 ABB words from the 6 syllables used in experiment 1 divided in A (le, zo, and ni) and B syllables (mo, ri, and ve). All other characteristics of the words and the visual stimuli were identical to the ones in experiment 1.

Procedure. The procedure and the scoring criteria were identical to experiment 1, except that all words presented in the preswitch phase followed one structure (e.g., AAB) and all words presented in the postswitch phase followed the other structure (e.g., ABB). The structure and phase pairing was counterbalanced across infants.

Experiment 3. ***Participants.*** Forty infants were included in the analysis [20 Italian monolinguals (10 girls) and 20 bilinguals (11 girls); age range, 7 months 3 days to 7 months 30 days]. Participants were recruited in Trieste, Italy and surrounding areas. All participants were healthy full-term infants. Fifteen bilinguals heard Italian and Slovenian, 1 heard Italian and Spanish, 1 heard Italian and English, 2 heard Italian and French, and 1 heard Italian and Russian. Fourteen infants were excluded (7 monolinguals and 7 bilinguals) because of fussiness or experimental error.

Stimuli. The visual cues were sequences of 3 simple geometrical figures. These sequences had identical figures either at the beginning (AAB) or at the end (ABB). We constructed 9 AAB and 9 ABB sequences from 3 A (arrow, circle, and pentagon) and 3 B (star, triangle, and moon) figures. The figures had a side-length of 4 cm (9.14°) and were different colors. The other visual stimuli were identical to the ones in experiments 1 and 2.

Procedure. The procedure and scoring were identical to experiments 1 and 2, except that instead of using speech cues we used sequences of simple figures following an AAB pattern in one phase and ABB in the other. The figures appeared sequentially in the center of the screen and were presented for 800 ms each, with a 300 ms interstimulus interval.

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