

Flexible Learning of Multiple Speech Structures in Bilingual Infants

Ágnes Melinda Kovács* and Jacques Mehler

Children acquire their native language according to a well-defined time frame. Surprisingly, although children raised in bilingual environments have to learn roughly twice as much about language as their monolingual peers, the speed of acquisition is comparable in monolinguals and bilinguals. Here, we show that preverbal 12-month-old bilingual infants have become more flexible at learning speech structures than monolinguals. When given the opportunity to simultaneously learn two different regularities, bilingual infants learned both, whereas monolinguals learned only one of them. Hence, bilinguals may acquire two languages in the time in which monolinguals acquire one because they quickly become more flexible learners.

Although the remarkable performance of children acquiring one language is impressive, many children acquire more than one language simultaneously. As bilingual children presumably have to learn roughly twice as much as their monolingual peers (because they learn two languages instead of one), one would expect their language acquisition to be somewhat delayed. However, bilinguals pass the language development milestones at the same ages as their monolingual peers (1). For instance, infants produce their first words around 1 year of age and produce 50 words around 18 months, irrespective of whether they learn one language or two (2).

How do bilingual children succeed in acquiring two languages as fast as monolinguals learn one? An indication of how bilinguals may accomplish this feat comes from other cognitive domains, where increased experience in a domain leads to more efficient processing, such as chess masters who are better at memorizing chess configurations than novices.

Possibly, bilingual children efficiently acquire two languages because of their greater experience in learning from a mixed input. In fact, bilinguals have to learn a distinct set of properties for each of the languages from a multilanguage input, while avoiding interference between the two languages. Thus, they might recruit specific mechanisms that help them to simultaneously extract patterns from two languages even before they start speaking. If so, bilingual infants might show specific enhancements in dealing with multiple regularities in linguistic stimuli early on.

In an eye-tracking study, we explored whether 12-month-old bilingual infants are better at simultaneously learning multiple speech structures than monolinguals. In each trial, infants listened to a trisyllabic speech item while watching a central attention-getter stimulus. Following this, an attractive toy appeared on the left or the right side of the screen (Fig. 1A). The

speech item's structure predicted the location of the toy. For example, if the speech item conformed to an ABA structure (where the first and the last syllables were identical), the toy appeared on the right side of the screen, whereas it appeared on the left side if the structure was AAB (experiment 1).

If infants have difficulties learning two structures simultaneously, they might still learn the

structure they find easier to process [that is, AAB (3), although studies have suggested that infants can learn either structure when exposed to just one of them (4)]. Our crucial prediction, however, is that 12-month-old bilinguals are already flexible enough in dealing with multiple speech structures to learn two structures simultaneously.

Infants were first exposed to 36 AAB and ABA familiarization trials in pseudo-random order. Then, they were tested in eight trials with novel items. In these test trials, the toy did not appear after the speech item (5). To assess whether infants learned the structures, we measured where they looked after hearing a new item. During the test phase, infants can predict where the toy should appear only if they learn that the structures determine its location. Thus, for looking to the correct side, infants had to extract and generalize the two structures and to link each structure to one of the locations. Our principal measure to assess learning was infants' first look after hearing the new speech item. If they learned the structures, they should first search for the toy where it used to appear for that specific structure. Difference scores [(number of correct looks – number of incorrect looks)/

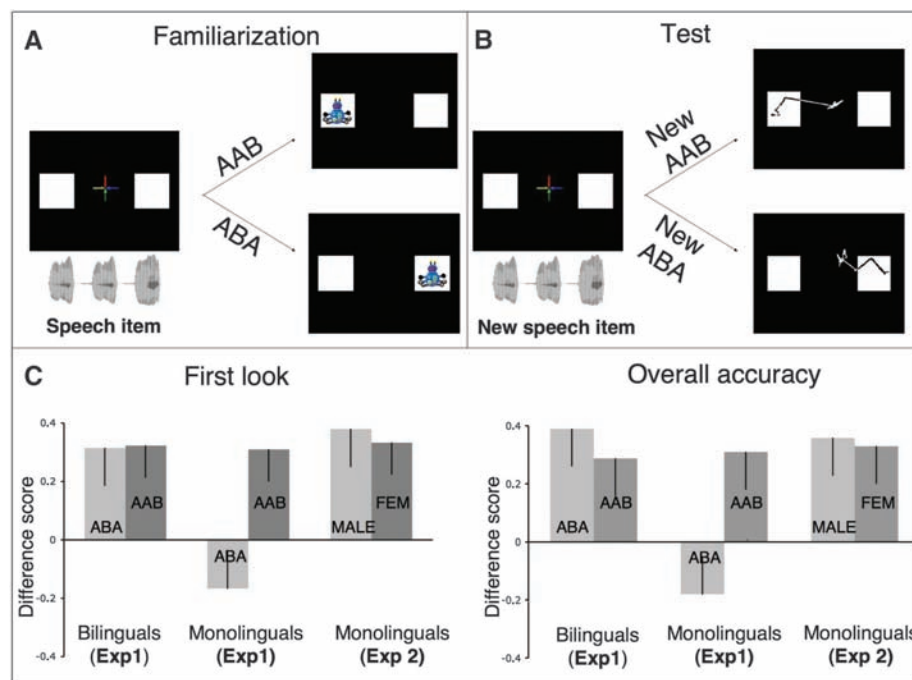


Fig. 1. (A) Familiarization phase of experiment 1. Infants listened to trisyllabic speech items where either the first two syllables were identical (i.e., an AAB structure, as in “lo-lo-vu”) or the first and last syllables were identical (i.e., an ABA structure, as in “lo-vu-lo”). Speech items were followed by a toy appearing in one of two white squares that were displayed continuously on the screen. The location of the toy was predicted by the item’s structure (e.g., left square for AAB, and right square for ABA). (B) Test phase of experiment 1. Infants were presented with new AAB and ABA items, but no toy followed the speech items. We used an eye-tracker to measure where the infants expected the toy to appear. On the right, two scan paths of an infant are depicted on two trials. (C) Measures of learning for the two structures or the two voice cues. Left: Difference scores for first looks [(number of correct looks – number of incorrect looks)/(number of correct looks + number of incorrect looks)] related to the chance level of 0 for ABA and AAB structures (experiment 1: bilinguals, $N = 22$; monolinguals, $N = 20$); and for male and female voices (experiment 2: monolinguals, $N = 20$). Right: Difference scores for overall accuracy for bilinguals and monolinguals in experiment 1 and for monolinguals in experiment 2. Error bars represent SE.

Scuola Internazionale Superiore di Studi Avanzati-SISSA, Via Beirut 4, 34014 Trieste, Italy.

*To whom correspondence should be addressed. E-mail: agneskovacs@mtapi.hu

(number of correct looks + number of incorrect looks)] were calculated for each structure and tested against a chance level of 0, as well as compared across groups and conditions. Second, we measured the infants' overall accuracy (6). That is, trials were scored as correct if the infant looked longer to the correct side within the 2 s after hearing a new item and before the start of the next trial. Difference scores were calculated for each structure as described above.

Bilinguals looked more often to the correct side for both structures during the test trials as shown by the first look analysis [AAB: $t(21) = 2.24$, $P = 0.03$; ABA: $t(21) = 3.76$, $P = 0.001$; Fig. 1C, left] and by the overall accuracy analysis [AAB: $t(21) = 2.14$, $P = 0.04$; ABA: $t(21) = 2.75$, $P = 0.01$; Fig. 1C, right]. Monolinguals, by contrast, looked more often to the correct side when the speech items had the structure AAB, but not when they had the structure ABA, as shown by the first look analysis [AAB: $t(21) = 2.37$, $P = 0.03$; ABA: $t(21) = -1.48$, $P = 0.15$] and by the overall accuracy analysis [AAB: $t(21) = 2.15$, $P = 0.04$; ABA: $t(21) = -1.43$, $P = 0.16$].

The overall analysis of variance with the factors Group (monolingual/bilingual) and Condition (AAB/ABA) on difference scores for first looks yielded a main effect of Group [$F(1,42) = 4.61$, $P = 0.03$] and, crucially, a Group \times Condition interaction [$F(1,42) = 5.44$, $P = 0.02$]. Post hoc tests show that monolinguals' performance for the ABA structure was worse than for the AAB structure (Bonferroni $P = 0.03$) and worse than the bilinguals' performance for the ABA structure (Bonferroni $P = 0.02$).

To exclude the possibility that bilinguals' advantage reflects just a better learning of con-

tingencies between sounds and locations, rather than their ability to learn multiple structural regularities, we ran an additional experiment involving only monolingual infants. In experiment 2, a new group of 12-month-old monolinguals heard speech items that differed not only in their structure but also in their pitch (e.g., female voice for ABA and male voice for AAB). Infants successfully learned to predict the toy locations based on the voices as shown by the first look analysis [female voice: $t(19) = 2.60$, $P = 0.01$; male voice: $t(19) = 2.94$, $P = 0.008$; Fig. 1C] and the overall accuracy analysis [female voice: $t(19) = 2.24$, $P = 0.03$; male voice: $t(19) = 2.59$, $P = 0.01$, Fig. 1C]. Together, the results of these experiments show that, in contrast to bilinguals, monolingual infants cannot learn two structures, although they can associate two speakers with different locations.

Twelve-month-old preverbal bilingual infants thus seem to be more flexible learners of multiple structural regularities than monolinguals. This flexibility might be related to different (mutually compatible) processes. Bilinguals might be better at learning two structures simultaneously. Alternatively, they might be better at avoiding interference between the two structures and quickly learn one of the structures and the corresponding toy location. This might even help them to learn the other structure and location. Although there is no evidence that such "reasoning by exclusion" is available to infants at this age, such ability might help infants to bootstrap new regularities from regularities they have already learned.

The advantage of bilinguals may be related to the precocious development of control and selection abilities, which has been documented in bi-

lingual children (7) and infants (8). These abilities may allow bilinguals to take advantage of sources of information unavailable in monolingual settings and to become better at simultaneously monitoring different structural regularities. This in turn may help them to learn more efficiently each of their languages. Such powerful learning abilities allow bilinguals to pass the linguistic milestones at the same rate as monolinguals.

References and Notes

1. J. F. Werker, K. Byers-Heinlein, *Trends Cogn. Sci.* **12**, 144 (2008).
2. B. Z. Pearson, S. C. Fernandez, D. K. Oller, *Lang. Learn.* **43**, 93 (1993).
3. J. Gervain, F. Macagno, S. Cogoi, M. Peña, J. Mehler, *Proc. Natl. Acad. Sci. U.S.A.* **105**, 14222 (2008).
4. G. F. Marcus, S. Vijayan, S. Bandi Rao, P. M. Vishton, *Science* **283**, 77 (1999).
5. Materials and methods are available as supporting material on Science Online.
6. B. McMurray, R. N. Aslin, *Infancy* **6**, 203 (2004).
7. E. Bialystok, *Child Dev.* **70**, 636 (1999).
8. A. M. Kovács, J. Mehler, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 6556 (2009).
9. We thank the parents and infants who participated in the study as well as A. D. Endress, G. Csibra, E. Téglás, and L. Bonatti for comments. We also thank the anonymous reviewers for helpful suggestions. This work was supported by the NEST PATHFINDER initiative "What it means to be human" (CALACEI), J. S. McDonnell Foundation, and Marie Curie 035975 DISCOS grants. Á.M.K. is currently at the Hungarian Academy of Sciences and at the Central European University, Budapest, Hungary.

Supporting Online Material

www.sciencemag.org/cgi/content/full/1173947/DC1
Materials and Methods

23 March 2009; accepted 19 June 2009

Published online 9 July 2009;

10.1126/science.1173947

Include this information when citing this paper.

Identification of Splenic Reservoir Monocytes and Their Deployment to Inflammatory Sites

Filip K. Swirski,^{1,*†} Matthias Nahrendorf,^{1*} Martin Etzrodt,^{1,2} Moritz Wildgruber,¹ Virna Cortez-Retamozo,¹ Peter Panizzi,¹ Jose-Luiz Figueiredo,¹ Rainer H. Kohler,¹ Aleksey Chudnovskiy,¹ Peter Waterman,¹ Elena Aikawa,¹ Thorsten R. Mempel,^{1,3} Peter Libby,^{4,5} Ralph Weissleder,^{1,6,†} Mikael J. Pittet^{1†}

A current paradigm states that monocytes circulate freely and patrol blood vessels but differentiate irreversibly into dendritic cells (DCs) or macrophages upon tissue entry. Here we show that bona fide undifferentiated monocytes reside in the spleen and outnumber their equivalents in circulation. The reservoir monocytes assemble in clusters in the cords of the subcapsular red pulp and are distinct from macrophages and DCs. In response to ischemic myocardial injury, splenic monocytes increase their motility, exit the spleen en masse, accumulate in injured tissue, and participate in wound healing. These observations uncover a role for the spleen as a site for storage and rapid deployment of monocytes and identify splenic monocytes as a resource that the body exploits to regulate inflammation.

Protection of injured or infected tissue involves migratory leukocytes (1–3). Among them are blood monocytes, which consist of at least two functionally distinct subsets (4, 5).

Ly-6C^{high} (Gr-1⁺) monocytes are inflammatory and migrate to injured (6, 7) or infected (8–10) sites but also propagate chronic diseases (11–13). Ly-6C^{low} (Gr-1⁺) monocytes patrol the resting

vasculature (14), populate normal (15) or inflammatory sites (14), and participate in resolution of inflammation (7).

Tissue repair after myocardial infarction (MI) requires coordinated mobilization of both subsets: first, Ly-6C^{high} monocytes digest damaged tissue; second, Ly-6C^{low} monocytes promote wound healing (7). We observed that the ischemic myocardium accumulates Ly-6C^{high} monocytes in numbers that exceed their availability in circulation (Fig. 1A), which intrigued

¹Center for Systems Biology, Massachusetts General Hospital and Harvard Medical School, Boston, MA 02114, USA. ²Faculty of Biology and Medicine, University of Lausanne, CH-1015 Lausanne, Switzerland. ³Center for Immunology and Inflammatory Diseases, Massachusetts General Hospital and Harvard Medical School, Charlestown, MA 02129, USA. ⁴Cardiovascular Division, Department of Medicine, Brigham and Women's Hospital, Boston, MA 02115, USA. ⁵Center for Excellence in Vascular Biology, Brigham and Women's Hospital, Boston, MA 02115, USA. ⁶Department of Systems Biology, Harvard Medical School, Boston, MA 02115.

*These authors contributed equally to this work.

†To whom correspondence should be addressed. E-mail: fswirski@mgh.harvard.edu (F.K.S.); rweissleder@mgh.harvard.edu (R.W.); mpittet@mgh.harvard.edu (M.J.P.)

This copy is for your personal, non-commercial use only.

If you wish to distribute this article to others, you can order high-quality copies for your colleagues, clients, or customers by [clicking here](#).

Permission to republish or repurpose articles or portions of articles can be obtained by following the guidelines [here](#).

The following resources related to this article are available online at www.sciencemag.org (this information is current as of June 21, 2015):

Updated information and services, including high-resolution figures, can be found in the online version of this article at:

<http://www.sciencemag.org/content/325/5940/611.full.html>

Supporting Online Material can be found at:

<http://www.sciencemag.org/content/suppl/2009/07/09/1173947.DC1.html>

This article **cites 7 articles**, 3 of which can be accessed free:

<http://www.sciencemag.org/content/325/5940/611.full.html#ref-list-1>

This article has been **cited by** 2 article(s) on the ISI Web of Science

This article has been **cited by** 8 articles hosted by HighWire Press; see:

<http://www.sciencemag.org/content/325/5940/611.full.html#related-urls>

This article appears in the following **subject collections**:

Psychology

<http://www.sciencemag.org/cgi/collection/psychology>