Bilingual Adaptations in Early Development

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Abstract

Infants raised in bilingual homes redirect attention faster than infants raised in monolingual homes. How can mere exposure to a bilingual environment affect an infant's cognitive development? The more complex language environment may drive infants to explore (gather more information from) their visual environment to facilitate learning.

A 'bilingual advantage' in infants?

Evidence is emerging that mere exposure to a bilingual environment can affect an infant's cognitive development. Specifically, 7- to 9-month-old infants from bilingual homes shift visual attention faster and more frequently than infants from monolingual homes [1]. They also appear to be quicker at updating a previously learned behavioural response: a within-trial, time course analysis [2] of data from three eye-tracking studies [1-3] found that bilingual infants who learned to anticipate the appearance of a visual stimulus on one side of a screen were faster at landing their anticipatory looks to the visual stimulus after it had begun to appear on the opposite side of the screen. Finally, 6-month-old infants from bilingual homes look longer at novel visual stimuli than infants from monolingual homes [4].

At first blush, the findings dovetail with findings of a purported bilingual cognitive advantage in older children and adults (the 'bilingual advantage'). The traditional explanation for the bilingual advantage is that managing two or more languages during *language production* draws upon, and thus strengthens, domain-general cognitive processes that select words in the intended language while inhibiting the activation of words in the unintended language (the 'inhibitory control model' [5]). However, 6- to 9-month-old infants generally do not *produce* language. Therefore, according to the inhibitory control model, young infants raised in bilingual homes should not yet develop a cognitive advantage.

This raises an important question: how can mere exposure to a bilingual environment affect an infant's cognitive development? All accounts put forward to answer this question so far remain underspecified [6]. Here, we aim to provide a theoretical framework that would unify emerging empirical evidence and drive the field forward.

Bilingual adaptations to fewer samples and greater volatility

All biological organisms, including human infants, adapt to their environment by modelling the ever-changing world and anticipating events within it. They do this by sampling, selecting, and

acting on the external world (resulting in different sensory input) and by altering their models and predictions accordingly. Infants who hear two or more languages ('bilingual infants') are likely to receive less input from each language than 'monolingual infants' from their one language.

What effect would fewer samples have on the developing child? At any particular moment in time, the bilingual infant will have had less experience with each of their languages than their monolingual peers. But this does not mean that they will behave like younger (less experienced) monolingual infants. The cognitive and sensorimotor systems of bilingual and monolingual infants are likely to develop at a similar rate. As these systems adapt and are honed to the external environment, they may be used to minimise the gap between the infant's model of the world and sparser speech input. For example, the bilingual infant may have limited control over the number of words they hear (until they are capable of inducing caregivers to label objects or engaging others in conversation), but they could facilitate their learning by sampling more visual information such as lip movements. Observing the shape and motion of a speaker's lips increases the ability of the listener to discriminate between speech sounds [7] and is associated with larger vocabulary sizes in toddlerhood (e.g. [8]). Indeed, 7- to 10-month-old infants are more likely to look at the mouth area if they are from bilingual homes than monolingual homes [9]. Moreover, developing cognitive and sensorimotor abilities may enable the bilingual infant to rapidly switch attention between a speaker's mouth and *competing stimuli* such as an object the infant is handling or the speaker's eyes, gaze, and gestures. These competition-driven, experience-dependent adjustments to the internal connectivity of the cognitive and sensorimotor systems may bias the bilingual infant to switch attention faster more generally (Figure 1). This would explain why bilingual infants switch attention between visual stimuli more frequently and more rapidly disengage attention from one stimulus in order to shift it to another [1]. It would also explain a range of other recent observations. For instance, a multi-laboratory study was set up to test the hypothesis that 6- to 9-month-old bilingual infants are better at gaze following than age-matched monolingual infants. The study did not find the expected 'bilingual advantage', but it did report that bilingual infants had unexpectedly made more frequent fixations to on-screen objects than monolingual infants [10]. Another study found that 4- to 10-month-old bilinguals orient faster to faces and make more fixations to faces than their monolingual peers [11]. Altogether, these studies demonstrate increased sampling of visual stimuli, which fits with our proposal that bilingual infants are driven to sample more from their (visual) environment.

In addition to receiving fewer samples from each language, samples in bilingual environments may be more varied, noisier, and less predictable than samples in monolingual environments. For example, a single utterance could contain phonemes and words from two different languages [12], and because bilingual parents may be more fluent in their native language, one language may contain more variation (e.g., pronunciation errors) than the other [13]. How would this affect the developing child? Infants may adapt to receiving fewer and more volatile samples by developing weaker top-down prior expectations and placing more weight on gathering information. This would explain a curious set of recent findings: whereas 7- to 9-month-old

bilingual infants were quicker at updating a previously learned behavioural response, monolingual infants were quicker at initially learning that behavioural response [1-3]. We suggest that the bilingual infants in these studies were slower at building and strengthening their expectations or representations during the initial learning phase – but as a consequence, required less time to reverse them. This may sound counterintuitive since an earlier study reported that a habituation slope to a visual stimulus was steeper in 6-month-old bilingual infants than in monolingual infants [4]. But curiously, in that study bilingual infants actually spent *more* time looking at the visual stimulus overall during the habituation period than monolingual infants. Although it was not reported, the combination of a steeper slope and more overall looking suggests that the bilingual infants *initially* looked more at the visual stimulus (i.e., when it was novel or less familiar). Furthermore, because average number of habituation trials was not compared between groups, it is possible that the bilingual infants habituated to the visual stimulus by the same trial as the monolingual infants, but only because they spent more time sampling the visual stimulus initially. After the bilingual and monolingual infants had habituated to the visual stimulus, the (now familiar) visual stimulus was presented alongside a novel visual stimulus. The bilingual infants looked longer at this novel stimulus than the monolingual infants. Altogether, greater looking at the novel stimuli (both at the beginning of the habituation phase and during the post-habituation phase) fits with our hypothesis that infants from bilingual homes find novel stimuli more salient.

The adaptations to sparser input and volatile environments could extend to longer timescales and other levels of description. Adapting to various environmental contingencies (e.g., in speech input) involves pruning and refining neural networks; the infant brain starts out with considerable plasticity and capacity to adapt to varying contingencies, but this plasticity declines over developmental time as different neural elements become progressively committed to particular functions, increasing the fit between the infant and its specific environment. If the bilingual infant brain receives fewer samples, is slower at building expectations, and places more weight on bottom-up sensory information, then it will also retain more plasticity. Evidence consistent with a more gradual decline in plasticity in bilingual infants already exists. For example, monolingual infants generally become less sensitive to non-native contrasts from 6 to 10 months of age, but remarkably, bilingual toddlers (English-Mandarin) in Singapore remain sensitive to remote African (Ndebele) click consonants as late as the second year of life (18-20 months) [14].

Summary and future directions

A new picture is emerging. The bilingual environment is likely to be more complex than the monolingual one. The way we expect organisms to adapt to more complex environments is to sample (explore) more of their visual environment, shift attention faster and more frequently, and be slower at building expectations. We think this could explain a great number of recent findings in the bilingual infant literature. But from every nascent field blossom questions. In what ways do bilingual environments differ from monolingual environments? In what ways do bilingual

environments differ from each other? Is there a trade-off between seeking novel information (exploring) and analysing (exploiting) familiar information? Is brain development merely prolonged in bilingual infants (i.e., until a sufficient amount of speech has been sampled from each language) or do the early adaptations have cascading effects on the developing system, altering its trajectory? Should bilingual trajectories be described as a 'bilingual advantage' or adaptive processes? Our hope is that by viewing infants as adaptive systems and answering these questions (Box 1), it will be possible to explain (rather than merely describe) how exposure to different language environments constrain infant cognitive development.

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References

1. D'Souza, D. et al. (2020) Is mere exposure enough? The effects of bilingual environments on infant cognitive development. *R. Soc. Open Sci.* 7, 180191
2. Pour Iliaei, S. et al. (2020) Bilingualism affects infant cognition: Insights from new and open data. *PsyArXiv*. Published online September 5, 2020. https://doi.org/10.31234/osf.io/ex76a
3. Kalashnikova, M. et al. (2021) The effects of bilingualism on attentional processes in the first year of life. *Dev. Sci.* 24, e13011
4. Singh, L. et al. (2015) Back to the basics: a bilingual advantage in infant visual habituation. *Child Dev.* 86, 294-304
5. Green, D. W. (1998) Mental control of the bilingual lexico-semantic system. *Biling.: Lang. Cogn* 1, 67-81
6. Costa, A. and Sebastián-Gallés, N. (2014) How does the bilingual experience sculpt the brain? *Nat. Rev. Neurosci.* 15, 336-345
7. Masapollo, M. et al. (2018) Asymmetries in unimodal visual vowel perception: The roles of oral-facial kinematics, orientation, and configuration. *J. Exp. Psychol. Hum. Percept. Perform.* 44, 1103-1118
8. Young, G.S. et al. (2009) Gaze behavior and affect at 6 months: predicting clinical outcomes and language development in typically developing infants and infants at risk for autism. *Dev. Sci.* 12, 798–814
9. Oakes, L. M. et al. (2021) Infant Eye Gaze While Viewing Dynamic Faces. *Brain Sci.* 11, 231
10. Byers-Heinlein, K. et al. (2021) The development of gaze following in monolingual and bilingual infants: A multi-laboratory study. *Infancy* 26, 4-38
11. Mercure, E. et al. (2018) Impact of language experience on attention to faces in infancy: Evidence from unimodal and bimodal bilingual infants. *Front. Psychol.* 9, 1943
12. Bail, A. et al. (2015) Look at the gato! Code-switching in speech to toddlers. *J. Child Lang.* 42, 1073
13. Bosch, L. and Ramon-Casas, M. (2011) Variability in vowel production by bilingual speakers: Can input properties hinder the early stabilization of contrastive categories? *J. Phon.* 39, 514-526
14. Singh, L. (2018) Bilingual infants demonstrate advantages in learning words in a third language. *Child Dev.* 89, e397-e413

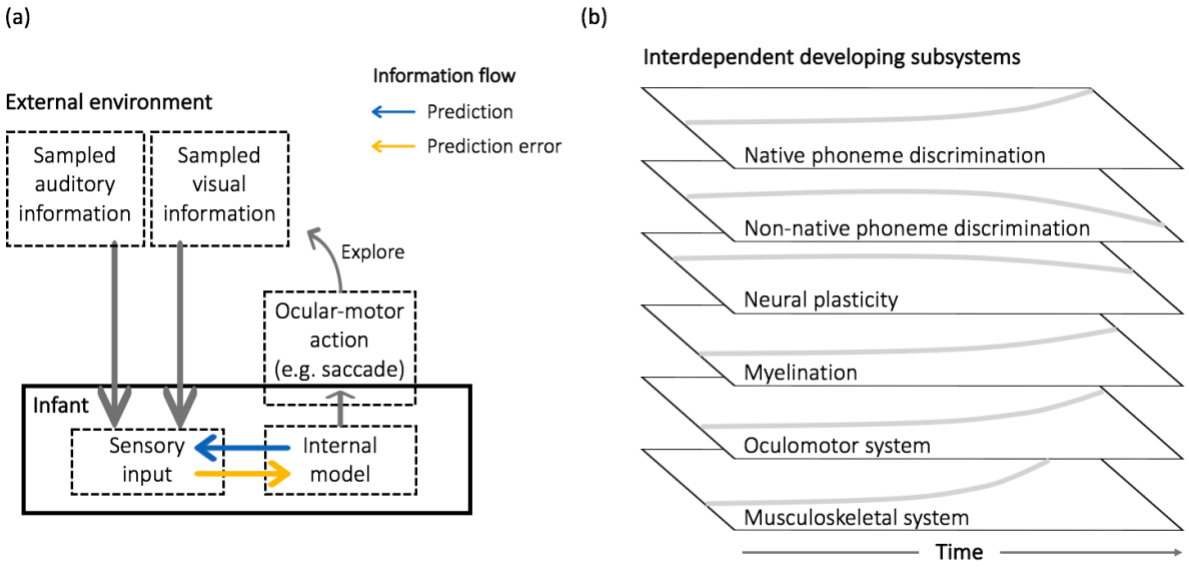

Figure 1 How bilingual infants adapt to their environment.

(a) Infants adapt to their environment by modelling the ever-changing world and anticipating events within it. They do this by sampling, selecting, and acting on the external world (resulting in different sensory input) and by altering their models and predictions accordingly. Infants who receive less auditory input from each language may be slower at building up an internal model of each language, and thus rely on visual information (e.g., lip movements) for an extended period of time. (b) Although infants may adapt to their environment by switching attention faster and more frequently, it is important to note that such behaviours emerge as a function of the self-organising cooperation of various interdependent subsystems within some context. So deeper insight will come from studying how each subsystem develops and interacts within the context of the infant and environment. This will reveal which behavioural patterns are tightly constrained and more likely to repeat over developmental time, and which are easily perturbed and transient. For example, the speed and frequency of switching attention may arise as a function of language experience and the interaction of developing musculoskeletal and oculomotor systems within the context of a complex environment and concurrent speech input.

Text Box

Box 1. Hypotheses

Infants adapt to their environment by minimising the difference between their model/predictions of the world and sensory information (see [1] for discussion). Different sensory input (e.g., language) may therefore result in different models and predictions. To minimise the difference between its model/predictions and sensory information, the infant samples, selects, and acts on the external world (resulting in new sensory information) and/or alters its models/predictions. Because bilingual homes provide fewer (and perhaps more varied and less predictable) samples from each language than monolingual homes, infants in bilingual homes may *sample* their external world differently and *adjust* their models/predictions accordingly. Based on recent data (see main text) we outline several (complementary) general proposals and specific hypotheses.

On a general level, infants may adapt to their fewer samples and more varied, less predictable environments by sampling more widely (collecting a greater range of samples), developing weaker top-down prior expectations (predictions), and placing more weight on bottom-up sensory evidence. In other words, the bilingual infant brain may calibrate or adjust its internal connectivity to the metrics of the external world in such a way that it errs on the side of exploration. Based on these broad proposals, we identify a number of more specific (testable) hypotheses:

(1) Although infants learn language primarily from infant-directed speech, bilingual infants are more likely to increase auditory input by shifting attention to speakers in the background.
(2) Bilingual infants are more likely than monolingual infants to switch attention between the objects they are handling and speakers.
(3) The more varied or unpredictable the language environment is, the more likely the infant will search their visual environment for supplementary information.
(4) Bilingual infants will encode or analyse (exploit) information in less depth than monolingual infants, in order to spend more time seeking new information (exploring).