Developmental Science

Developmental Science 12:5 (2009), pp 815–823 DOI: 10.1111/j.1467-7687.2009.00902.x

PAPER

Monolingual, bilingual, trilingual: infants' language experience influences the development of a word-learning heuristic

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Abstract

How infants learn new words is a fundamental puzzle in language acquisition. To guide their word learning, infants exploit systematic word-learning heuristics that allow them to link new words to likely referents. By 17 months, infants show a tendency to associate a novel noun with a novel object rather than a familiar one, a heuristic known as disambiguation. Yet, the developmental origins of this heuristic remain unknown. We compared disambiguation in 17- to 18-month-old infants from different language backgrounds to determine whether language experience influences its development, or whether disambiguation instead emerges as a result of maturation or social experience. Monolinguals showed strong use of disambiguation, bilinguals showed marginal use, and trilinguals showed no disambiguation. The number of languages being learned, but not vocabulary size, predicted performance. The results point to a key role for language experience in the development of disambiguation, and help to distinguish among theoretical accounts of its emergence.

Introduction

A hallmark of children's language development in the second year of life is their emerging ability to rapidly learn new words. One factor that likely contributes to rapid word learning is children's capacity to infer the meaning of new words in underspecified contexts. For example, in the presence of a cup and an unfamiliar object such as a garlic press, children tend to associate a novel word like 'zav' with the garlic press rather than with the cup (Markman & Wachtel, 1988). This heuristic of mapping a novel word onto a novel object is known as disambiguation (Merriman & Bowman, 1989). Disambiguation is often understood as the product of a word-learning constraint, one of many biases that allow children to limit the scope of plausible referents that they consider for the meaning of a novel word. Investigating how such constraints operate and where they come from is foundational to understanding the feat of lexical acquisition.

Most of the research to date investigating disambiguation has focused on children's underlying motivation for mapping the novel noun onto the novel object. Several accounts posit a socio-pragmatic origin of this heuristic. Clark, for example, has proposed that children understand that different words come from different underlying intentions (1987, 1990). This gives rise to the principle of contrast, whereby children assume that different words must contrast in meaning. Similarly, Diesendruck and colleagues have suggested that disambiguation comes from pragmatic understanding. Children infer that a novel word applies to a novel object (or one without a known name) because, had a particular speaker wanted a familiar object nameable by the child, that speaker would have used the conventional name (Diesendruck & Markson, 2001).

Other accounts of disambiguation are conceptual rather than social in nature. Markman and colleagues have suggested that disambiguation is a manifestation of the larger principle of mutual exclusivity, a 'default assumption' that each object should have one basic-level label (Markman & Wachtel, 1988; Markman, 1992). Under the mutual exclusivity account, children show disambiguation because they first reject the nameable object as a referent for the new label, and then search for a novel object. Another proposal, the Novel-Name Nameless Category assumption (N3C; Mervis & Bertrand, 1994; Mervis, Golinkoff & Bertrand, 1994) suggests that children disambiguate novel nouns because they are motivated to find a name for each object.

The question of how disambiguation first develops has received considerably less attention than investigations of children's underlying motivation for the heuristic. Word learning and disambiguation do not develop synchronously: instead, infants' first understanding of highly frequent words such as 'mommy' and 'daddy' can

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be seen as early as 6 months (Tincoff & Jusczyk, 1999), while disambiguation appears later, between 16 and 18 months of age (Halberda, 2003; Markman, Wasow & Hansen, 2003). Why is disambiguation unavailable at the onset of word learning? Different accounts of disambiguation provide different hypotheses. Socio-pragmatic accounts imply that children must achieve a certain level of socio-pragmatic understanding before they can show disambiguation, and this may not occur until well after their first birthday. The N3C account proposes that children must learn sufficient words in order to have the conceptual insight that each object should have a name (Mervis & Bertrand, 1994; Mervis *et al*., 1994). The mutual exclusivity account remains agnostic as to the origins of the constraint, and why it emerges when it does. As Markman and colleagues have stated, 'Whether and what kinds of exposure to linguistic input are relevant to working out this assumption remains an open question' (Markman *et al*., 2003, p. 272).

Here we test the possibility that language experience contributes to the development of disambiguation. The current studies take a cross-linguistic approach by comparing disambiguation in infants learning a single language to disambiguation in those learning multiple languages. Multilingual children are of particular theoretical interest, as they must learn a basic-level label in each of their languages for each object (one in each language), in apparent contradiction to constraints such as mutual exclusivity. Several studies of preschoolers and school-aged children have found that bilinguals show a weaker tendency to disambiguate novel nouns than monolinguals do (Davidson, Jergovic, Imami & Theodos, 1997; Davidson & Tell, 2005; but see also Frank & Poulin-Dubois, 2002; Merriman & Kutlesic, 1993). Reported differences could originate in the initial development of disambiguation, or might come about as children gain increased social and linguistic experience during their preschool years. A comparison of monolingual and multilingual infants near the onset of the use of disambiguation could disentangle these two possibilities. If disambiguation differs between monolinguals and multilinguals from the get-go, this would provide strong evidence that language experience influences the development of disambiguation, and not just its later use.

We used a preferential looking-while-listening paradigm (Fernald, Pinto, Swingley, Weinberg & McRoberts, 1998; Golinkoff, Hirsh-Pasek, Cauley & Gordon, 1987; Halberda, 2003) to test infants between 17 and 18 months old, the age when disambiguation is first shown in monolingual infants (Halberda, 2003; Markman *et al*., 2003; Mervis & Bertrand, 1994). Participating infants were all of the same chronological age, but differed with respect to their early language experience: infants grew up in either monolingual, bilingual, or trilingual homes. Different accounts of disambiguation and its developmental origins yield different predictions about the relative performance of each group. If disambiguation emerges on a maturational timetable, infants should show similar performance on a disambiguation task regardless of language background. If the development of disambiguation is related to socio-pragmatic competence, then there is no particular reason to predict any differences between the groups as all would have had a similar amount of social experience. If language experience itself influences the development of disambiguation, then markedly different types of early experience might change the developmental timetable of disambiguation. In such a case, an examination of factors that predict infants' success in disambiguation, such as vocabulary size and the number of languages being learned, might provide important clues as to how disambiguation develops.

Study 1

Method

Participants

Forty-eight infants participated in Study 1, 16 each from monolingual, bilingual, and trilingual backgrounds. Half in each group were female. They ranged in age from 17m8d to 18m20d, and mean ages for the monolingual, bilingual, and trilingual groups respectively were 17m28d, 17m29d, and 18m1d. Eleven additional infants were tested but excluded due to restlessness (7), crying (2), disinterest in the procedure (1), and parental report of poor vision (1).

Language background

Monolingual infants came from English-speaking homes, and their parents reported that they had not received any systematic exposure to a language other than English. Multilingual infants had been exposed to English as well as either one other (bilinguals) or two other (trilinguals) languages in the home since birth. The non-English languages reported in the sample were diverse, including 22 different languages (see Appendix for full details of multilingual infants' language backgrounds). Exposure to each of the multilinguals' languages was measured by the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997). For bilingual infants, a minimum of 25% exposure to each language was set as an inclusion criterion (Pearson, Fernandez, Lewedeg & Oller, 1997), and bilinguals heard a mean of 48% English (range: 27 to 70%), and 52% of their other language (range: 29 to 73%). For trilingual infants, perfectly balanced exposure would result in hearing each language 33% of the time. Therefore, for trilinguals we accepted a more relaxed minimum exposure to each language. On average, trilinguals heard English 37% of the time (range: 19 to

55%), and each of their two other languages 32% of the time (range: 19 to 55%).

Vocabulary measure

Estimates of infants' English vocabulary size were obtained by asking parents to complete the Words and Gestures form of the MacArthur-Bates Communicative Development Inventory (MCDI; Dale & Fenson, 1996; Fenson, Marchman, Thal, Dale & Bates, 2007), which has shown high validity in at least one bilingual sample (Marchman & Martinez-Sussman, 2002). For multilingual infants, parents were asked to complete the form with respect to only their child's English vocabulary, and when possible, the caregiver who spoke English most often with the infant filled out the form. MCDI data could not be collected for bilingual and trilingual infants' non-English languages due to the unavailability of versions of the MCDI for many of the languages represented. Vocabulary data were not available for two monolinguals, one bilingual, and one trilingual, because their caregivers failed to return a completed form. Reported English receptive and productive vocabulary sizes were highest for monolinguals, and lowest for bilinguals, with the trilinguals between the other two groups (see Table 1).

Stimuli

Visual stimuli consisted of four brightly colored objects, three familiar (ball, car, and shoe) and one novel. The novel object was a slightly modified version of a phototube from the TarrLab Object DataBank (1996). The objects were presented on a black background in consistent pairs: car–ball and phototube–shoe. The objects appeared in different colors on different trials to maintain infant interest, and to ensure generalization across different-colored exemplars of the same object category. Sample stimulus pairs are shown in Figure 1.

Auditory stimuli were recorded by a female native English speaker who spoke in an infant-directed manner. The stimuli consisted of three labels that named the familiar objects – 'ball', 'car', 'shoe', and one label that named the novel phototube object – 'nil'. Although 'nil' does have meaning for English-speaking adults, its infrequent use and abstract meaning make it unlikely that infants are familiar with this word.[1] Each label was recorded in isolation, and with three carrier phrases, 'Look at the ___', 'Find the ___', and 'Where is the ___'. For each trial, the label was presented once embedded in a carrier phrase (chosen quasi-randomly), and again in isolation (e.g. 'Look at the ball! Ball!').

Table 1 *English MCDI scores for infants in Study 1*

	Receptive vocabulary			Productive vocabulary		
	M	*SD*	Range	*M*	*SD*	Range
Monolinguals	260	66	156–374	76	84	7–285
Bilinguals	156	72	32–313	35	29	1–109
Trilinguals	202	118	20–367	75	92	4–267

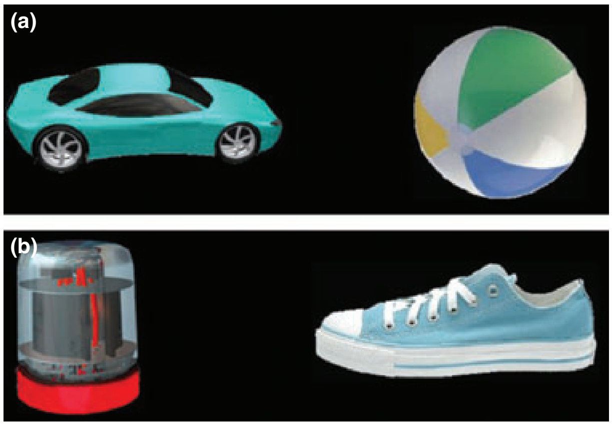

Figure 1 *Sample stimulus pairs: (a) Car–ball pair; (b) Phototube–shoe pair.*

To ensure that infants were likely to know the familiar words used in this study, we examined infants' reported comprehension on the corresponding MCDI items. Comprehension within each language exposure group of 'ball', 'car', and 'shoe' ranged from 80 to 100%. Therefore across all three groups, the vast majority of infants understood these words.

Apparatus

Data were collected using a Tobii 1750 eye tracking system with the following components: a monitor that both presented the stimuli and recorded infant eye-gaze, and a PC computer running the Tobii Clearview software program that controlled the stimulus presentation and collected the eye tracking data. Light-emitting diodes built into the monitor generated invisible infrared light, which shone on the infant's face. A high-resolution camera built into the monitor collected eye-gaze data based on the light reflection off the infant's cornea relative to the pupil.

Procedure

The study was conducted in a dimly lit, sound-attenuated room. Infants sat on their parent's lap, approximately 60 cm away from the eye tracking monitor. Loudspeakers

[1] It is also relevant whether 'nil' was a word known to multilingual infants in a language other than English. No parents of participants in the study reported that their infants knew a meaning for the word 'nil' in any language. Further, 'nil' is either phonotactically illegal or is a non-word in the most frequent languages in our sample: French, Cantonese, Mandarin, Spanish, Tagalog, Vietnamese, and Japanese.

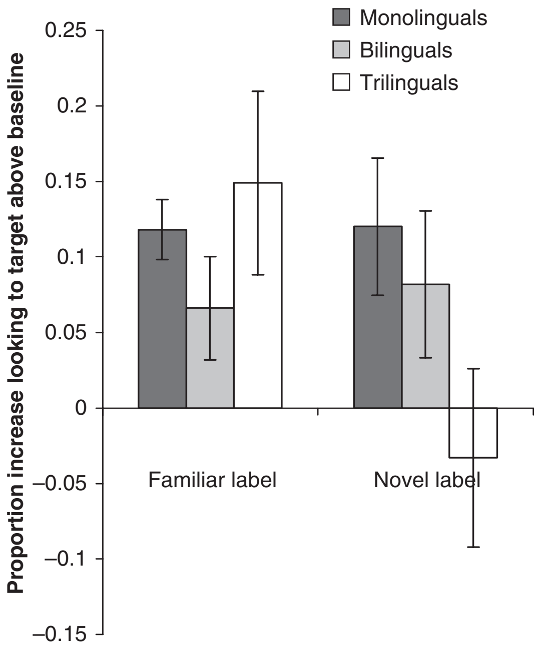

Figure 2 *Proportion increased looking towards target objects as a function of language exposure group.*

were located on either side of the monitor, hidden from view by a black cardboard panel. To avoid influencing the infant during the study, parents wore a blindfold or closed their eyes. The experimenter controlled the study from a computer and a closed-circuit TV monitor, out of sight of the infant. Prior to the study, a 5-point infant calibration routine calibrated the eye tracker to the infant's eyes.

Each session started with a warm-up trial, during which a spinning waterwheel appeared sequentially on each side of the monitor. Following the warm-up, infants were presented with experimental trials. On each trial, the object pair first appeared in silence on the monitor for 3 seconds, so that infants' baseline preference for each object could be measured. The test phase of the trial immediately followed the baseline phase, when an auditory stimulus was played that named one of the objects (e.g. 'Look at the ball! Ball!'). The objects then remained in silence on the monitor, such that the total trial length was 9.5 seconds. After the test phase was completed, the unlabeled object disappeared, while the labeled object (or the novel object in the case of novel label trials) moved around on the monitor for 2 seconds with accompanying music. Previous studies of word comprehension have suggested that such visual feedback keeps infants on-task in preferential looking studies (Killing & Bishop, 2008). The results of the current and past studies have found no evidence that this reinforcement drives infants' performance on novel label trials (see Results; Halberda, 2003).

Infants were presented with 24 test trials, in four blocks of six trials per block, in an experimental design similar to that used by Halberda (2003). The first and third blocks consisted of known vs. known trials (ball–car), while the second and fourth blocks consisted of known vs. novel trials (shoe–nil). Each object was labeled on half of the trials in which it appeared, thus a total of six times. Each infant saw the objects in a consistent configuration throughout all the trials (e.g. ball on left, car on right). Eight stimulus orders were created to counterbalance side and order of presentation across infants. A bright circular pattern was presented in the center of the monitor between trials to ensure that trials began with a central visual fixation. The total duration of the study was approximately 7 minutes.

Infant eye-gaze data were collected at 20 ms intervals by the eye tracker, and each time interval was classified as a look towards the left side object, a look towards the right side object, or no look towards either object. Data were equated to the onset of each label for each trial, so that they could be collapsed across trial type in order to measure the infant's success at orienting to the labeled object.

Results and discussion

Infants' responses to familiar and novel words were examined in a window that began 360 and ended 2000 ms after the onset of the target word. A number of other studies investigating word comprehension in infants and adults have used a similar initial time point as a plausible minimum time required to respond to a word, due to the time needed both to process the word and to initiate an eye movement (e.g. Dahan, Swingley, Tanenhaus & Magnuson, 2000). Looking time after 2000 ms post-word-onset is less likely to be in response to the word itself (Fernald, Perfors & Marchman, 2006; Swingley & Fernald, 2002). Only trials with sufficient attention during the first 2 seconds post-word-onset, i.e. those with more than 750 ms of looking to the two objects, were included. Seventeen percent of all trials were excluded due to insufficient attention.

An individual baseline score was calculated for each infant, as the proportion of time the infant looked at a particular object during the 3 second silent baseline period on all trials in which that object was onscreen. Trials during which the infant looked less than 1 out of the 3 seconds were excluded from the calculation. For shoe–nil trials, a 2 (object type: familiar, novel) × 3 (language background: monolingual, bilingual, trilingual) ANOVA showed that infants had an overall preference for looking at the familiar object during baseline over the novel object, $F(1, 45) = 24.62$, $p < .0005$, but this did not interact with language background, $F(2, 45) = .056$, $p = .946$. This replicates previous findings that infants prefer to look at objects with known names over other objects (Schafer, Plunkett & Harris, 1999; White & Morgan, 2008). Thus, to control for inherent baseline preferences, all subsequent analyses were conducted with difference scores, which subtracted each individual's baseline preference from the proportion of time they looked at the target object after labeling. A positive difference score therefore indicates increased looking at the target object after labeling.[2]

Familiar label trials were analyzed first, to assess whether infants understood the task. Success would be shown by an increase in looking at the target object. One-tailed *t*-tests on infants' familiar label difference scores confirmed that monolinguals, $M = .12$, $SD = .079$, $t(15) = 5.97$, $p < .005$, $d = 1.49$, bilinguals, $M = .066$, $SD = .13$, $t(15) = 1.96$, $p = .035$, $d = .49$, and trilinguals, $M = .14$, $SD = .243$, $t(15) = 2.46$, $p = .014$, $d = .61$, all increased looking to the target object upon hearing its label. A one-way ANOVA confirmed no significant differences among language exposure groups $F(2, 45) = 1.01$, $p = .37$.

To examine infants' ability to disambiguate the novel noun by increasing their attention to the novel object, one-tailed *t*-tests were performed on infants' difference scores for novel label trials. Monolinguals showed a strong disambiguation effect, significantly increasing attention to the novel object upon hearing a novel label, $M = .12$, $SD = .18$, $t(15) = 2.63$, $p = .0095$, $d = .66$. Increased attention to the novel object was seen on the first five of the six experimental trials. Bilinguals showed a similar but marginal pattern, $M = .08$, $SD = .19$, $t(15) = 1.69$, $p = .057$, $d = .42$. Bilinguals' average difference score was positive on all six experimental trials. Trilinguals showed no increase in looking towards the novel object upon hearing the novel label, $M = -.033$, $SD = .24$, $t(15) = -.563$, *ns.*[3] Their average difference score was positive on three and negative on three trials. To assess whether infants' performance improved across trials due to the feedback provided after each trial (when the target object moved on the screen to music), a linear trend analysis was performed separately for each group. This analysis showed that infants' performance did not improve over successive trials, as there was no significant linear trend for monolinguals, $F(1) = 1.86$, $p = .25$, bilinguals, $F(1) = .081$, $p = .802$, or trilinguals, $F(1) = .404$, $p = .55$. Results for both familiar label and novel label trials are presented in Figure 2.

[2] Note that this type of approach uses an individual measure of chance (baseline score), rather than a blanket criterion of chance such as 50%. As such, a positive difference score does not necessarily reflect an overall preference for the target after labeling, but rather an increase in looking to the target relative to baseline.

[3] To ensure that this pattern of results was not an artifact of the 360–2000 ms window of analysis, additional analyses were conducted on the 2000–4000 ms time window. Results were almost identical to those found in the earlier window. One-tailed *t*-tests showed that monolinguals showed strong disambiguation, $M = .13$, $t(15) = 2.69$, $p = .009$, $d = .67$, bilinguals showed marginal use of disambiguation, $M = .11$, $t(15) = 1.72$, $p = .057$, $d = .43$, and trilinguals showed no evidence of using disambiguation, $M = .04$, $t(13) = .76$, $p = .23$, $d = .20$. The trilingual results here are based on 14 infants as two of the participating infants lost interest during the later part of each trial.

A linear regression analysis was performed to investigate what aspects of infants' language proficiency and experience predicted performance on novel label trials. The use of linear regression preserves the inherent ordering of the groups in terms of the number of languages infants are learning (monolingual < bilingual < trilingual), a feature of our experimental design which cannot be modeled by techniques such as ANOVA or ANCOVA. The number of languages being learned by the infant was a significant predictor of infants' difference scores, $\beta = -.317$, $t(44) = -2.02$, $p = .05$, while English MCDI comprehension, $\beta = -.008$, $t(44) = -.04$, $p = .97$, and production scores, $\beta = -.048$, $t(44) = .26$, $p = .80$, showed almost no association with performance.

Study 2

Method

To rule out the possibility that any incidental aspects of the procedure drove infants' responses, Study 2 was run as a control study. The procedure was identical to that of Study 1, except that object label phrases (e.g. 'Look at the ball! Ball!') were replaced with no-label attention phrases. Three attention phrases were used: 'Look at that! Look!', 'Can you see it? Wow!' and 'There it is! Look!' Visual stimuli were unchanged. That is, on each trial, one object of the pair moved on the screen accompanied by music as it did in Study 1; however, the particular object that moved was unrelated to the attention phrase.

Sixteen infants (half female) participated. Nine of the participants were from monolingual English-speaking families, and seven were from bilingual families. Data from an additional nine infants were excluded due to disinterest in the procedure (4), crying (2), restlessness (2), and equipment failure (1). Bilinguals' exposure to their languages was assessed as in Study 1, and bilingual infants were reported to hear English an average of 49% of the time (range: 28 to 68%) and their other language an average of 50% (range: 28 to 72%) of the time. One bilingual infant was hearing a small amount (8%) of a third language. Because of experimenter error, MCDIs were collected for only half of the infants: five monolinguals and three bilinguals. These infants had an average receptive vocabulary of 261 ($SD = 98$; range: 153–452) and productive vocabulary of 77 ($SD = 77$; range: 19–190), making their vocabulary sizes comparable to those of monolinguals in Study 1.

Results and discussion

Infants' difference scores were analyzed as in Study 1. One-tailed *t*-tests showed that infants did not significantly increase looking to the target object on familiar label trials, $M = .07$, $SD = .14$, $t(15) = .45$, $p = .33$, $d = .5$. On novel label trials, infants showed a small decrease in attention to the novel object after hearing the no-label attention phrase, $M = .082$, $SD = .19$, $t(15) = -1.59$, *ns*. Infants' failure to engage in systematic looking behavior confirms that incidental aspects of the experimental procedure cannot account for their performance in Study 1, and replicates, with an older age group, a similar study conducted by Halberda (2003).

General discussion

The current research sought to determine whether early language experience influences the development of a word-learning heuristic: the disambiguation of novel nouns by associating them with novel referents. We tested three groups of infants aged 17–18 months who were growing up learning different numbers of languages: monolinguals, bilinguals, and trilinguals. Monolinguals showed disambiguation strongly (replicating Halberda, 2003, who tested English-learners at a similar age), bilinguals showed marginal use of disambiguation, and trilinguals showed no disambiguation. Incidental aspects of the experimental procedure did not drive the result, as those infants that showed disambiguation did so from the very first trial, and infants responded randomly in a control study in which a no-label attention phrase was used rather than a novel label. Further, the results cannot be explained by generalized differences in performance in a preferential looking task, as all three groups succeeded on familiar label trials, while differing only on novel label trials. Our results clearly demonstrate that early language experience influences the development of disambiguation (see Houston-Price, Caloghiris & Raviglione, 2009, for a recent extension).

Established accounts of disambiguation can be distinguished by their predictions concerning the role of language experience in infants' development of this heuristic. The mutual exclusivity account is agnostic, stating that the developmental origins remain unknown. Socio-pragmatic accounts suggest that social understanding, rather than language experience, should underlie developmental differences in disambiguation across infants. Existing research to date comparing socio-pragmatic development in monolinguals and bilinguals has mostly investigated theory of mind development, and has shown that bilingual children outperform monolinguals in theory of mind tasks (Goetz, 2003; Kovács, 2009). While there is disagreement about whether this advantage stems from social (Goetz, 2003) or cognitive (Kovács, 2009) bases, the existing research predicts that if anything, multilingual children should be superior to monolingual children in social understanding. Under socio-pragmatic accounts, this would imply a precocious ability to disambiguate novel nouns, a pattern opposite to our results.

Could the N3C account explain our results? The N3C account proposes that children are only able to disambiguate novel nouns once they acquire enough words to have the insight that all objects have a name (Mervis & Bertrand, 1994). In the current study, our three language exposure groups did differ with respect to English vocabulary size, but this did not account for our results. A regression analysis revealed that neither English production nor English comprehension vocabulary size predicted performance on novel label trials. Further, if English vocabulary size drives the development of infants' ability to disambiguate novel English words, then trilinguals should have outperformed bilinguals as they had larger vocabularies, but this was not the case.

Considering only English vocabulary size underestimates bilingual and trilingual infants' lexical knowledge because these infants also know words in their non-English languages (De Houwer, Bornstein & De Coster, 2006; Pearson, Fernandez & Oller, 1993). Due to the numerous different languages represented in the current study, non-English vocabularies could not be measured. Could the use of disambiguation be tied to total vocabulary size across all languages, rather than English vocabulary size? Several studies of bilingual infants and toddlers have suggested that bilinguals know the same or more words than their monolingual peers when both languages are taken into account (Junker & Stockman, 2002; Pearson *et al.*, 1993). In the current study, exposure to various languages was fairly balanced among the multilingual groups. Assuming that these infants knew on average the same number of other-language words as they did English-language words, their total vocabulary size would have been even larger than that of the monolingual group, which would yield precocious disambiguation by the multilinguals, and not the decreased use of disambiguation that we found. Although lack of data on infants' non-English vocabularies means that this possibility cannot be totally ruled out, vocabulary size across languages is unlikely to account for the results of the current study.

How then might experience in a multilingual environment influence the development of disambiguation? Our results showed that the degree to which infants showed disambiguation co-varied with the number of languages they were learning: the more languages being learned, the less the infants showed disambiguation. We suggest that the development of disambiguation is influenced by the structure rather than the size of the vocabulary. As they learn their two languages, bilingual children often acquire cross-language synonyms or translation equivalents (De Houwer *et al.*, 2006; Junker & Stockman, 2002; Pearson *et al.*, 1993; Pearson, Fernandez & Oller, 1995). Translation equivalents represent a departure from the one-to-one mapping between word and concept that is typical of monolingual vocabularies. Trilinguals might know even more translation equivalents than bilinguals. Language experience could influence early disambiguation because knowledge of many-to-one mappings delays its development in the multilingual, because knowledge of one-to-one mappings promotes its development in the monolingual, or through an interplay of both factors.

In the past, researchers have reasoned about how word-learning biases may influence the early lexicon, by suggesting that bilinguals' knowledge of translation equivalents can be seen as evidence against one-to-one mapping biases such as mutual exclusivity and therefore in favor of other biases such as N3C (Golinkoff, Mervis & Hirsh-Pasek, 1994, p. 144). This argument sees word-learning biases and related heuristics such as disambiguation as coming online before early lexical knowledge is acquired. However, our results suggest the reverse: that lexical knowledge, in particular the knowledge of translation equivalents, precedes and ultimately influences the development of disambiguation. This 'lexicon structure hypothesis' could be tested and refined empirically by studies of monolingual and multilingual infants that relate their use of disambiguation to the number of one-to-one versus many-to-one mappings that their lexicons contain.

Recent computational accounts of disambiguation can also be invoked to consider how differences in disambiguation between monolinguals and multilinguals might arise due to the structure and content of their respective lexicons. These accounts posit that when listeners hear a novel word, an activation fraction is computed for each candidate referent, in our case a novel object and a familiar object (Merriman, 1999; Regier, 2003). The activation fraction is computed by summing the activation the candidate referent receives from the novel word (forming the numerator) and dividing by the activation that a candidate object receives from all words in the lexicon (the denominator). The numerator of the activation fraction is similar for both the familiar and novel objects, as it is mostly a function of noise in the system. The denominator is larger for the familiar object than for the novel object because the familiar object is activated by many words in the lexicon, while the novel object is not. Because they have similar numerators but the novel object has a smaller denominator, the activation fraction of the novel object is larger than that of the familiar object. This makes it more likely that the novel word will become associated with the novel object.

For multilinguals, known words from both languages may contribute to the denominator of the activation fraction, as a number of studies have shown that words from both the task language and other languages are active when bilingual adults perform auditory comprehension tasks (Blumenfeld & Marian, 2007; Spivey & Marian, 1999). Similarly, if words in multiple languages are activated for infants performing disambiguation tasks, multilinguals' activation ratio for the familiar object in response to the novel word would be even smaller than monolinguals', as words from multiple languages are associated with the familiar object. All else being equal, then, multilinguals would show even stronger disambiguation than bilinguals do, which is opposite to the pattern we found. Admittedly, computational accounts of disambiguation have thus far not explicitly addressed the multilingual situation, and further it is likely that *all else is not equal* between monolinguals and multilinguals in tasks such as disambiguation. Nevertheless our evidence is incompatible with current computational accounts of disambiguation. An expansion of computational accounts that reflects how multilinguals process, represent, and negotiate among their languages, and the role that translation equivalents might play, seems warranted.

How multilingual infants negotiate among their languages has other implications for a full understanding of disambiguation. Our study presented infants with a novel English noun in the context of a novel object and a shoe, a highly familiar object for which infants likely knew a word in each of their languages. However, multilingual infants may sometimes encounter a novel noun in the context of a novel object and a familiar object that they can only name in one of their languages. From a word-learning perspective, the interpretation of the novel noun should depend on whether the task language (the language in which the novel noun is embedded) matches the language in which the infant can name the familiar object. When that known word is in the same language as the task (e.g. the infant knows the English word 'shoe', and a novel word is presented in an English carrier phrase) looking at the novel object in response to the novel word is a case of within-language disambiguation. Like disambiguation in monolinguals, within-language disambiguation allows bilinguals to avoid unlikely referents for new words, as it is unlikely that 'shoe' has two English labels. However, if that known word is in the other language (e.g. the infant knows the French word 'chaussure', and the novel word is presented in an English carrier phrase), then looking at the novel object in response to a novel noun would be a case of between-language disambiguation. Between-language disambiguation might interfere with making correct word–object associations, as a child might avoid a correct referent for an object simply because they already know a word for the object in another language. Two- and 3-year-old bilinguals sometimes show this non-adaptive, between-language disambiguation (Frank & Poulin-Dubois, 2002), while older bilinguals are more likely to understand that objects may have different names in different languages (Au & Glusman, 1990).

Critically, the ability of bilinguals to apply disambiguation only in a within-language context, and to avoid applying it between languages, rests on their ability to differentiate their two languages. Thus far, there has been little consensus as to when bilinguals understand that different words are part of different languages, and even less is known about when they are able to apply such knowledge in the service of word learning (for a review, see Paradis, 2001). Further studies of disambiguation in bilinguals might simultaneously be able to inform the debate on language differentiation in bilinguals, and further illuminate our understanding of word-learning heuristics. To the extent that bilingual infants differ in within-language versus between-language disambiguation, this implies that (a) bilinguals differentiate words as belonging to two languages and (b) disambiguation stems from the knowledge of an appropriate noun for the familiar object rather than the novelty of the novel object.

The developmental origins of word-learning biases remain largely unexplored. The current work significantly advances our understanding of these biases by showing that different types of early language experience influence the emergence of one elemental word-learning heuristic. More broadly, these results point to the utility of systematic investigations of different forms of early language experience as a means for better understanding fundamental mechanisms in language acquisition.

Acknowledgements

This work was funded through grants from the Social Sciences and Humanities Research Council of Canada (SSHRC), the McDonnell Foundation, and the Human Frontiers Science Program (HFSP) to JFW, and graduate fellowships from the Natural Sciences and Engineering Research Council of Canada (NSERC), the Killam Trust, the O'Brien Foundation, and the Canadian Federation of University Women to KBH. We are grateful to Jasmine Cady, Vivian Pan, Jessica Deglau, Sarah Heller and Clarisa Markel for their help with participant recruitment, and to members of the Infant Studies Centre for their important feedback and support. Thank you to Justin Halberda and three anonymous reviewers for their helpful and detailed comments on earlier versions of this manuscript. Special thanks to all of the parents and babies who participated in these studies.

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Received: 25 September 2008
Accepted: 9 February 2009

Appendix

Study 1 background information for multilingual participants

Participant	Background	Lang. A	%A	Lang. B	%B	Lang. C	%C
1	Bilingual	English	34	Croatian	66	–	–
2	Bilingual	English	48	Hebrew	52	–	–
3	Bilingual	English	61	French	39	–	–
4	Bilingual	English	60	Czech	40	–	–
5	Bilingual	English	42	Japanese	58	–	–
6	Bilingual	English	52	French	48	–	–
7	Bilingual	English	27	Portuguese	73	–	–
8	Bilingual	English	38	Kachi	62	–	–
9	Bilingual	English	60	Vietnamese	40	–	–
10	Bilingual	English	53	Spanish	47	–	–
11	Bilingual	English	71	Kachi	29	–	–
12	Bilingual	English	38	Spanish	62	–	–
13	Bilingual	English	54	Japanese	46	–	–
14	Bilingual	English	53	German	47	–	–
15	Bilingual	English	51	Punjabi	49	–	–
16	Bilingual	English	29	French	71	–	–
17	Trilingual	English	23	Japanese	45	French	32
18	Trilingual	English	30	Mandarin	50	Cantonese	20
19	Trilingual	English	21	Japanese	39	Italian	40
20	Trilingual	English	51	Tagalog	30	Ilocano	19
21	Trilingual	English	55	Hokkien	24	Mandarin	21
22	Trilingual	English	25	Spanish	55	Hungarian	20
23	Trilingual	English	43	Vietnamese	34	Cantonese	23
24	Trilingual	English	49	Cantonese	29	Vietnamese	22
25	Trilingual	English	46	Cantonese	34	Mandarin	20
26	Trilingual	English	47	Punjabi	33	Tagalog	20
27	Trilingual	English	32	Cantonese	37	French	31
28	Trilingual	English	20	Cantonese	50	Korean	30
29	Trilingual	English	19	Dutch	52	Arabic	29
30	Trilingual	English	45	Tagalog	28	Ilocano	27
31	Trilingual	English	35	Hebrew	32	Polish	33
32	Trilingual	English	44	Spanish	37	German	19