Input Affects Uptake: How Early Language Experience Influences Processing Efficiency and Vocabulary Learning

Anne Fernald, Virginia A. Marchman, and Nereyda Hurtado

Abstract— **Two studies explore how early vocabulary learning is influenced both by maternal speech to the child and by the child's developing skill in real-time comprehension. Study 1 shows that amount and quality of mothers' speech predict language growth in Spanish-learning children, providing the first evidence that language input shapes speech processing efficiency as well as lexical development. Study 2 demonstrates that early efficiency in speech processing is beneficial for vocabulary growth, showing how fluency in online comprehension facilitates learning.**

Index Terms—**cognitive science, language development, speech processing**

I. INTRODUCTION

INFANTS begin to understand and produce words and sentences through interaction with experienced speakers of the language they are learning. While most children become increasingly proficient over the first few years, they also vary considerably in their rate of learning new words [1]. One robust correlate of individual differences in early lexical development is variation in the quantity and quality of the language children hear from caregivers. Several studies show that English-learning children who hear more speech and more diverse vocabulary in daily interactions learn new words more quickly than do those who hear less child-directed speech [2]. A second factor correlated with individual differences in early language learning is variation in the efficiency with which children interpret spoken language. A recent longitudinal study using real-time measures of comprehension found that infants who were faster to identify familiar words had larger vocabularies than those who were slower [3]. Moreover, faster processing speed, reflecting more efficient "uptake" of lexical information, was associated with more accelerated vocabulary growth across the entire second year.

Our goal in this paper is to examine how early language input, vocabulary learning, and the early development of processing efficiency are interrelated. First we review research on how the quantity and quality of speech heard by the child relate to lexical development, and how the child's emerging skill in interpreting speech also relates to lexical development. Then we present two new studies that provide insight into how these different factors are integrated. Study 1 reveals that differences in mothers' speech at 18 months are directly associated with differences in children's processing efficiency at 24 months. Study 2 uses an online comprehension task to show that children who are faster to interpret familiar words early in the sentence are more successful in learning a novel word that comes later.

A. Caregiver Talk and Language Outcomes

Early studies examining consequences of caregiver talk asked whether the incidence of particular syntactic constructions predicted children's learning of those constructions [4]. Specific links were difficult to identify, but further research using more global measures converged on a surprising finding – that the sheer quantity of talk to the child influences language learning. Huttenlocher et al. [2] found that the amount of speech middle-class mothers addressed to their children was robustly related to rate of vocabulary growth from 14 to 26 months. Hart and Risley [5] examined child-directed speech in a broader demographic range, discovering even greater variability in the quantity and nature of caregiver talk. By their estimate, parents from professional families directed thousands more words to their children each day than did parents from working-class and welfare families, and these "meaningful differences" in early language experience predicted long-term cognitive outcomes. While this association could be an artifact of inherited verbal ability, similar links are seen among unrelated individuals. Moreover, caregiver talk predicts outcomes even after controlling for children's earlier vocabulary, ruling out the explanation that more talkative children simply elicit more speech from caregivers. Finally, in studies of English-learning children from different socioeconomic (SES) backgrounds, Hoff [6] showed that variation in language outcomes is directly attributable to characteristics of caregiver talk.

B. Speech Processing Efficiency and Vocabulary Development

Clarifying the role of the environment in language development also requires understanding the learning

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principles that guide young children's use of information available in the input. Several studies have explored how variation in vocabulary development is predicted by infants' efficiency in processing speech sounds. Recent results show how auditory processing, phonological discrimination, and segmentation in the first year relate to lexical development, based on procedures assessing perception of speech sounds not yet meaningful to preverbal infants. Using an eye-tracking procedure that requires infants to listen for meaning in speech, several cross-sectional studies have found associations between faster word recognition and more advanced linguistic development in both English [7]–[8] and Spanish [9]-[10]. In a longitudinal study, we found that faster processing speed at 25 months was associated with more rapid vocabulary learning across the second year [3]. Moreover, processing speed and vocabulary knowledge at 25 months strongly predicted performance on standardized tests of language and cognition at 8 years, showing that infants' early efficiency in interpreting language and building a working lexicon has long-term predictive validity [11].

C. Linking Caregivers' Speech to Children's Processing Speed and Vocabulary Learning

These findings suggest that children who are faster to identify familiar words in fluent speech are also better word learners. The most general explanation is that caregiver talk influences both language processing and vocabulary knowledge, and these links are independent and non-overlapping. Or it could be that vocabulary knowledge and speed of language understanding are interrelated, working together to take advantage of the multiple cues to meaning available in the input. For example, children exposed to richer caregiver input may be more practiced at interpreting words in continuous speech, and this increased practice could enable them to learn more words. In this case, correlations between caregiver talk and vocabulary size would be attributable to early experiences that facilitate children's skill in processing language in real time. It is also possible that relations between processing and vocabulary work in the other direction: Children who hear more talk may develop more robust phonological and lexical representations that are more easily accessed in real-time. In this case, it could be vocabulary knowledge itself that leads to the development of greater efficiency in speech processing.

To explore these questions further, we used an observational design in Study 1 to assess mothers' speech in relation to children's language outcomes, and an experimental design in Study 2 to test the hypothesis that children who were faster to identify familiar words in real-time comprehension would also be more successful in learning a novel word that followed.

II. STUDY 1

A. Overview

In Study I we examine links between Latina mothers' child-directed speech at 18 months and children's vocabulary at 18 and 24 months, an association documented previously in English- but not in Spanish-learners. Next, we ask whether children's vocabulary size also relates to their efficiency in identifying familiar nouns in fluent speech, and whether individual differences in speech processing, like vocabulary knowledge, are grounded in children's early language experience. In a series of multiple regression models we then assess the proposal that children's processing speed and vocabulary knowledge work together to allow more efficient uptake of the information that is available in caregiver talk.

B. Method

Participants. This research was conducted in a community-based laboratory in a low-income neighborhood, staffed by bicultural/bilingual Spanish-speaking researchers. Twenty-seven mother-child dyads participated when children were 18 and 24 months. Most parents were recent immigrants from Mexico with low English proficiency; all reported Spanish as the only language spoken at home. Most parents had less than a high-school education. Nearly 90% reported income less than required to cover basic expenses. Estimates of SES were based on the Hollingshead Four Factor Index of Social Status (HI) [12], revealing a mean HI of 24.3, with 70% of the families in the lowest two social strata.

Mothers' speech. At the 18-month visit, mothers were asked to play with the child for 20 minutes, using age-appropriate toys. Sessions were video- and audio-recorded. All maternal and child utterances were transcribed following ChiLDES protocols [13]. Following previous studies [2], [14], four measures of maternal speech were assessed: (1) number of utterances, (2) number of word tokens, (3) number of word types, (4) mean length of utterance (MLU). At 18 and 24 months, parents completed the *MacArthur-Bates Inventario del Desarrollo de Habilidades Comunicativas: Inventario II* [15], reporting on their child's productive vocabulary.

Speech processing. Efficiency in online comprehension was assessed at 18 and 24 months using the looking-while-listening procedure [16]. On each trial, children saw pictures of two familiar objects and heard speech naming one of them. Gaze patterns were coded frame-by-frame, yielding a high-resolution record of eye movements aligned with target noun onset. Speech stimuli consisted of simple sentences ending with a target noun *(¿Dónde está el/la [target]? 'Where's the [target]?'*). The 8 target nouns *(el perro, el libro, el jugo, el globo, el zapato, el plátano, la pelota, la galleta)* were familiar to most children learning Mexican Spanish at this age. Stimuli were acoustically analyzed and edited using Peak 4.0 LE software. Visual stimuli were pairs of digitized pictures, matched for visual salience and grammatical gender of object name. Mean reaction time (RT) for each child was based on trials when the child started on the distracter and shifted to the target picture within 300-1800 ms from target-word onset.

C. Results

Although there was considerable variation in the quantity, diversity, and complexity of mothers' speech, these measures were highly intercorrelated. Mothers who produced more

utterances also used more word tokens, $r(27)=.86$, $p<.001$, and types, $r(27)=.56$, $p<.01$, than those who said fewer utterances, and mothers who spoke more also used more different words, $r(27)=.80$, $p<.001$, and longer utterances, $r(27)=.68$, $p<.001$.

Mothers' speech and children's vocabulary at 18 months were also uncorrelated. In contrast, numbers of utterances and word tokens in mothers' speech at 18 months were significantly correlated with children's vocabulary at 24 months, after controlling for vocabulary at 18 months. Thus, variability in children's vocabulary was linked to the amount of language input experienced, over and above variance attributable to the child's vocabulary six months earlier. Spanish-learning children whose mothers used more words and utterances at 18 months also had larger increases in vocabulary from 18 to 24 months, consistent with studies of English-speaking mothers and infants [17].

While mean RT and vocabulary were uncorrelated at 18 months, this correlation was significant at 24 months, $r(27)=-.55$, $p<.01$. Those children with faster RTs at 24 months knew more words than did those with slower RTs. Faster children also showed larger vocabulary gains from 18 to 24 months, consistent with reports that efficiency in language processing and vocabulary growth are linked across the second year [3].

The next analyses examined maternal talk as a predictor of children's processing efficiency. Although maternal talk and child RT were uncorrelated at 18 months, measures of maternal talk were significantly correlated with children's RT at 24 months, accounting for 18-26% of the variance. Relations remained after partialling out RT at 18 months, indicating that the influence of input on processing speed was over and above variance attributable to the child's own processing efficiency 6 months earlier. Thus, children whose mothers used more and more complex talk at 18 months were faster to process spoken language six months later. Mothers were divided by median split based on the number of words in their child-directed speech at 18 months, as shown in Figure 1. Those 24-month-olds whose mothers had produced more words at 18 months identified the target picture more quickly and reliably than did those with less talkative mothers.

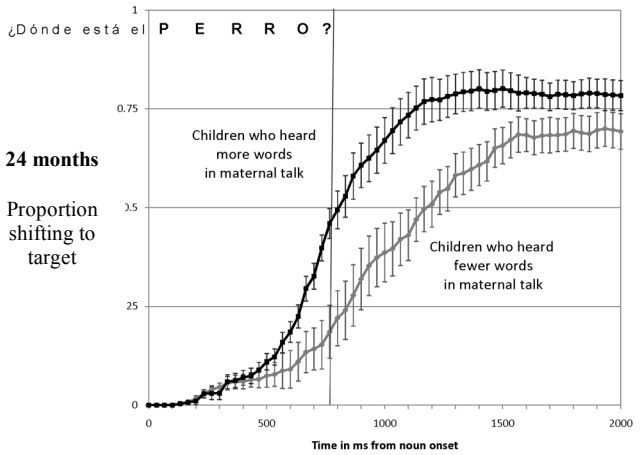

Figure 1. Mean proportion of trials on which 24-month-olds shift correctly from distracter to target picture as a function of maternal speech characteristics at 18 months. Solid vertical line represents target noun offset; error bars represent SEs over participants.

We next examined independent vs. overlapping influences of processing speed and lexical development. In Figure 2, panel A shows the strength of the direct vs. indirect effects of maternal talk on vocabulary, with processing speed serving as a potential mediator. The direct effect of maternal talk accounts for 14% of the variance ($p < .03$). However, the path coefficient is reduced substantially after controlling for processing speed (unique r^2 = 4%, *ns*), suggesting that caregiver talk exerts an influence on vocabulary via processing speed. Panel B tests another model in which maternal talk influences processing speed with vocabulary as the mediating variable. Maternal talk directly accounts for 21% of the variance ($p < .01$), yet that relation is no longer significant after controlling for vocabulary (unique r^2 = 7%, *ns*). In both cases, effects of maternal talk are significantly diminished with a mediator included in the model. These findings argue against a general explanation that links between processing speed and lexical development are reducible to their independent relations to caregiver talk, suggesting instead that language processing and vocabulary knowledge are synergistically related in the context of a unified learning system.

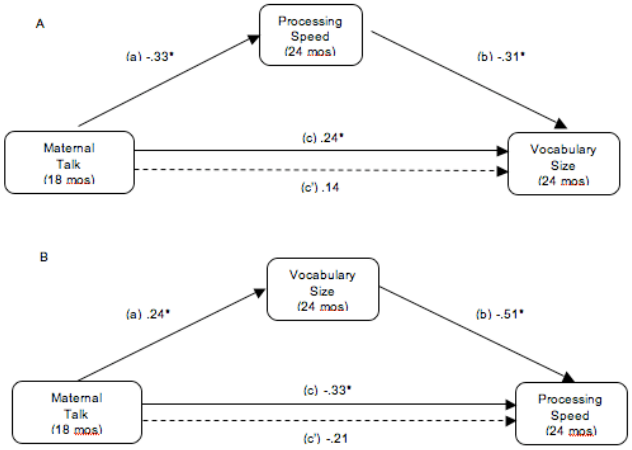

Figure 2. Regression analyses of links between maternal talk at 18 mos and child vocabulary and mean RT at 24 mos, controlling for vocabulary at 18 mos. Unstandardized coefficients are reported for direct and indirect relations between maternal talk and vocabulary (Panel A) and processing speed (Panel B). In both models, (a) presents the path coefficients for maternal talk and the potential mediator, (b) shows the unique relation between mediator and dependent variable, (c) gives total effect of maternal talk on the dependent variable, and (c') presents the direct effect of maternal talk after mediator has been included in the model. Dashed lines represent non-significant effects. In both cases, non-parametric bootstrapping estimation with bias corrected confidence intervals (BC CIs) [18] indicated that the indirect effects (i.e., c – c') were significantly greater than zero, supporting the interpretation of mediation (Processing: point estimate = .14, CI: .01 to .38; Vocabulary: point estimate = -.12, CI: -.01 to -.37).

D. Discussion

This longitudinal study of the impact of mothers' talk to Spanish-learning children revealed four main findings: First, there was substantial variability in maternal talk within this low-SES sample, and differences in input were associated with children's vocabulary outcomes. Children of mothers who talked relatively more heard on average 7 times more words, 5 times more utterances, 3 times more different words,

and sentences twice as long as those heard by children of less talkative mothers. Children who heard more caregiver speech had larger vocabularies at 24 months and made greater gains in vocabulary. These links remained strong after controlling for child variables at 18 months, thus are not attributable to the child's own level of talkativeness. Second, children with larger vocabularies at 24 months were also faster to identify familiar words in fluent speech at that age. As in the Fernald et al. [3] longitudinal study, Spanish-learning children who had faster mean RTs at 2 years had greater gains in vocabulary from 18 to 24 months, compared to children with slower RTs.

Third, we discovered a link between early language input and the development of speech processing efficiency by the child. The quantity and quality of caregivers' speech at 18 months predicted children's efficiency in understanding at 24 months. Controlling for child RT at 18 months, those children whose mothers produced more words and more complex utterances during the play session at 18 months were significantly faster in online comprehension six months later than those who had heard less maternal talk. This finding provides the first evidence that individual differences in the early efficiency of language processing are related to the linguistic input children experience in day-to-day interactions.

These results show that the influence of children's early experiences with language goes beyond traditional measures of language competence: maternal talk is associated not only with children's vocabulary learning but also with the development of efficiency in real-time language processing. However, the fourth and most exciting result was that these relations represent primarily overlapping influences between maternal talk and child outcomes.

We modeled this coupling in two ways. In the first model, processing speed mediates the relation between language input and children's vocabulary knowledge (Figure 2A). Maternal speech could facilitate vocabulary development because children who hear more caregiver talk are more practiced in skills directly implicated in word learning, such as parsing speech [19], accessing semantic representations [20], or monitoring distributional cues to meanings or grammatical categories [21]. Children more experienced in lexical access may require fewer exposures to a word to achieve the same level of lexical detail as children with less practice, and thus may have more resources available to interpret unfamiliar words later in the sentence. In these ways, efficiency in speech processing is shaped by children's early experiences with caregiver speech, accounting for the relation between input and vocabulary knowledge reported here and elsewhere.

The second model emphasizes a path of influence in the reverse direction: vocabulary knowledge mediates the relation between language input and processing speed (Figure 2B). More caregiver talk exposes children to more varied exemplars of words in context, yielding a richer database of lexical and morphosyntactic cues to meaning. Hearing more words enables children to encode increasingly subtle distinctions among lexical forms [22], and to abstract higher-order lexical-semantic and morphosyntactic regularities that obtain within and across words [23]. As the lexicon grows, more refined processing skills are required to discriminate among words with phonetic overlap and other potentially confusable representations [24]. Increases in vocabulary size have also been linked to greater facility in word retrieval [25], [26], and to learning new words in a single exposure [27]. Thus, changes in the size and density of the lexicon could help to fine-tune speech processing skills.

These models are both consistent with the findings reported here. Together they suggest that early language input affects both processing efficiency and vocabulary knowledge, which are mutually influential in a bidirectional fashion. An increase in processing efficiency could enable faster word learning, while an increase in lexical knowledge could further sharpen the processing skills required to interpret increasingly complex and diverse strings of words. Thus vocabulary learning and fluency in lexical access act in interdependent ways within a unified system of language knowledge and real-time use. Caregiver talk not only guides the end-products of vocabulary learning, but also sharpens the processing skills used during real-time language comprehension.

III. STUDY 2

A. Overview

Study 1 confirmed our earlier findings that infants who are faster and more efficient in identifying familiar words in fluent speech are also more advanced in lexical development [3], [9], with the new discovery that gains in both processing speed and vocabulary size are predicted by the richness of the child's early language experience. Study 2 explores more deeply the link between early processing efficiency and vocabulary growth, to determine whether differences in young children's skill in online comprehension are related to their success in an implicit word-learning task.

The hypothesis tested was that those 36-month-olds who are faster to interpret a familiar object name encountered in an adjective-noun phrase early in a spoken sentence will be more successful in learning a novel object name encountered later in the same sentence. The predicion is that those children who are more efficient in lexical access in real-time interpretation of familiar words will have the attentional capacity to attend to subsequent unfamiliar words in the speech stream, relating them more effectively to potential referents in the visual array. In contrast, if identifying the referent of a familiar word requires more time and processing resources for children who are less efficient in lexical access, this will interfere with the opportunity to learn an unfamiliar word downstream.

B. Method

Participants. Thirty two 36-month-old children participated in Study 2, all from families in which English was the primary language spoken in the home.

Design and Stimuli. In an implicit word-learning task, children were presented on Exposure Trials with pairs of pictures in which two familiar objects of the same type (cups, bears, shoes), differing only in color (red, blue), were perched

on two different unfamiliar structures, a yellow pedestal and a green arch, as shown in Figure 3. Speech stimuli consisted of recorded sentences that were naturally spoken but carefully matched for duration of critical words. On 4 Exposure-Target trials, children heard sentences containing a familiar noun preceded by a color word in medial position, with a novel noun in final position, e.g. *There's a blue cup on the deebo!* On 4 Exposure-Distracter trials, sentences contained the same adjective-noun phrases, but with no novel noun, e.g. *There's a blue cup over there!* Thus children's attention was drawn equally often to the two novel objects, only one of which was named Each novel object served as the *deebo* for half the children, and each familiar object appeared with both novel objects for each child.

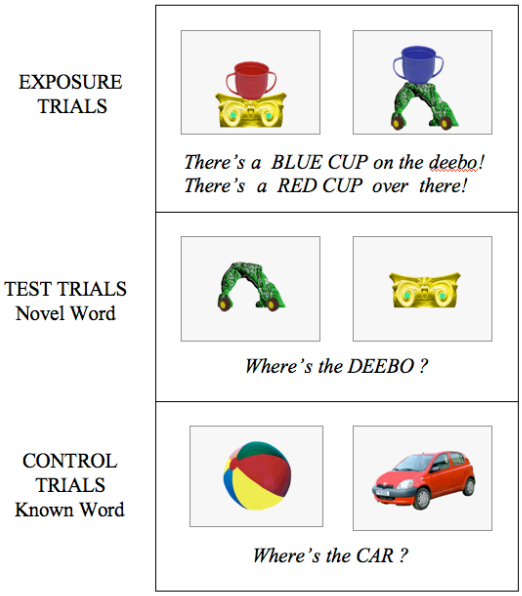

Figure 3. Examples of visual and auditory stimuli in Study 2.

These stimuli were designed to increase the processing load on Exposure trials. When choosing between a blue car and a red car, adults interpret the phrase *blue car* incrementally, using the prenominal adjective to identify the referent before the noun is spoken [28]. Although 3-year-olds typically produce these color words correctly, interpreting adjective-noun phrases is surprisingly difficult for young language learners, and many children at this age still have difficulty integrating the property term and the object name, resulting in a brief disruption in processing [29]. Our prediction was that those children who were more efficient in integrating the color word with the familiar noun would orient more quickly to the correct familiar object, and thus would be more likely to link the unfamiliar word at the end of the sentence (on Exposure-Target trials) with the novel object in the same picture.

The 8 Exposure trials were interspersed with 8 Control trials on which children heard simple sentences ending in familiar nouns with no adjective (e.g. *Where's the ball?*), followed by 4 Test trials, on which children saw the two novel objects with no other object present, and heard *Where's the deebo?*

Procedure. The looking-while-listening procedure [16] was used for both the Exposure and Test phases. In a booth with a rear-projection screen, children looked at pairs of pictures while listening to speech referring to one of the pictures. Gaze patterns were videorecorded and analyzed frame-by-frame by coders blind to trial type and target location, yielding a high-resolution record of the time course of children's responses precisely time-locked to the unfolding speech signal.

Measuring reaction time (RT). Speed of response to the target word was measured on distracter-initial trials on which a shift to the appropriate picture occurred within 300-1800 ms from target word onset, a time window based on previous analyses of shift distributions for 18- to 21-month-olds [7]. Shifts prior to 300 ms were excluded because they occurred before the child had time to process sufficient acoustic input and mobilize an eye movement, and shifts >1800 ms were excluded as outliers less clearly in response to the target word. On Exposure trials, RTs were measured from the acoustic onset of the prenominal adjective; on Control and Test trials, RTs were measured from the onset of the target noun.

C. Results

On Exposure trials some children were much faster than others in identifying the referent of the adjective-noun phrase, as predicted. Children were divided into a Faster RT group (M = 610 ms) and a Slower RT group (M = 980 ms) based on a median split of mean RTs on Exposure trials. The time course of responses by children in the Faster and Slower RT groups on Exposure trials is shown in Figure 4. Note that the faster children were able to take advantage of the prenominal adjective to identify the referent, orienting to the correct picture before the object was named. As a consequence of this efficient response, when they heard the unfamiliar word *deebo* milliseconds later, they were well positioned to map the novel word onto the correct novel object. In contrast, half the children in the Slower RT group were still looking at the incorrect picture as the familiar target noun was spoken, and thus were fixating the wrong novel object when they heard the word *deebo*.

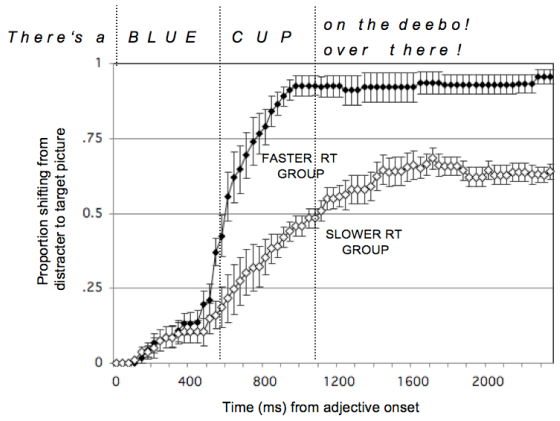

Figure 4. Time course of correct shifting to the target picture named in the adjective-noun phrase on Exposure trials. Children are divided into Faster and Slower RT groups based on median split of mean RTs. Dashed lines represent adjective and noun offsets; error bars represent SEs over participants.

Were those children who interpreted the adjective-noun phrase more rapidly also more successful in mapping the novel word *deebo* to the correct novel object? Figure 5 shows that children classified as faster or slower on Exposure trials did not differ on the Control trials, when the processing task was much simpler. However, on Test trials there were significant differences in both speed and accuracy (p<.001) in identifying the correct referent of the novel word. The Faster RT children succeeded in learning which novel object was the referent of the novel word *deebo*, while the Slower RT children did not.

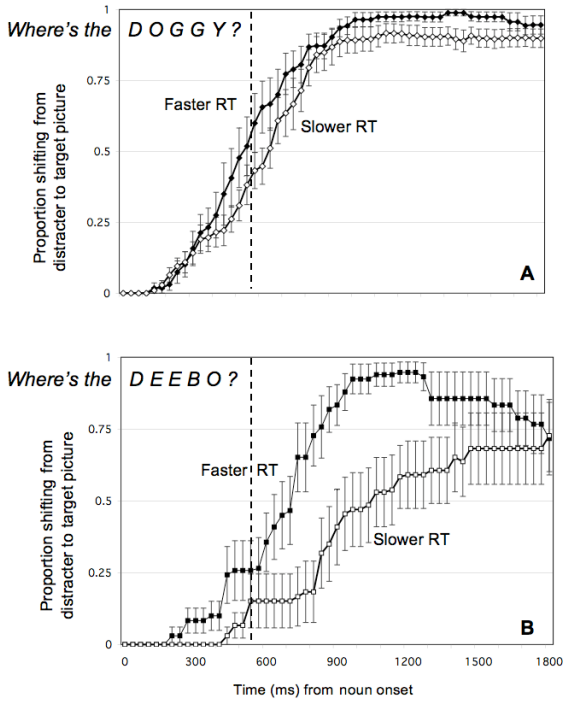

Figure 5. Mean proportion of trials on which children shifted correctly to the picture named by the target noun on (A) CONTROL trials with known words and (B) TEST trials with the novel word.

These results provide a compelling demonstration of the benefits of early processing efficiency for vocabulary growth. They also highlight the potential *cost* to children with less efficient processing skills, in terms of missed opportunities for learning. If providing children with rich linguistic experience is central in helping them develop fluency in understanding, as we found in Study 1, then the results of Study 2 reveal one way in which such early fluency could have long-term consequences for language and cognitive development.

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