Published in final edited form as:
Child Dev. 2012 January ; 83(1): 203–222. doi:10.1111/j.1467-8624.2011.01692.x.

Individual Differences in Lexical Processing at 18 Months Predict Vocabulary Growth in Typically-Developing and Late-Talking Toddlers

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Abstract

Using online measures of familiar word recognition in the looking-while-listening procedure, this prospective longitudinal study revealed robust links between processing efficiency and vocabulary growth from 18 to 30 months in children classified as typically-developing (*n* = 46) and as "late talkers" (*n* = 36) at 18 months. Those late-talkers who were more efficient in word recognition at 18 months were also more likely to "bloom", showing more accelerated vocabulary growth over the following year, compared to late-talkers less efficient in early speech processing. Such findings support the emerging view that early differences in processing efficiency evident in infancy have cascading consequences for later learning and may be continuous with individual differences in language proficiency observed in older children and adults.

Children vary substantially in early lexical development. Some grow rapidly in vocabulary production over the 2nd year, speaking more than 250 words by 18 months, while others begin to build a lexicon more slowly, speaking fewer than 10 words at this age (Fenson et al., 2006). Although delayed onset of expressive language can be a risk factor for later language and academic difficulties (Rescorla, 2009), early delays are often short-lived. Nearly two-thirds of late talkers move into the normal range before preschool, and distinguishing transient from persistent delays is notoriously difficult for clinicians and researchers (Dale, Price, Bishop & Plomin, 2003). Even studies that take multiple predictor variables into account report low predictive validity from infancy to later childhood (Law, Boyle, Harris, Harkness & Nye, 2000). In this research we provide the first evidence that individual differences in the efficiency of real-time verbal processing in infancy predict vocabulary growth from 18 to 30 months, both in typically developing children and in children classified as "late talkers."

Although language disorders in older children are associated with limitations in information processing skills (Montgomery, 2002), little is known about how processing efficiency relates to vocabulary growth in at-risk populations earlier in development. However, research using real-time measures of comprehension in typically-developing (TD) infants reveals robust relations between speech processing efficiency and linguistic development from 12 to 25 months. Longitudinal analyses show that speed and accuracy in language understanding at 2 years not only predict more accelerated vocabulary growth across the second year (Fernald, Perfors & Marchman, 2006), but also predict better language and cognitive outcomes at 8 years of age (Marchman & Fernald, 2008). Here we ask whether efficiency in real-time language understanding also predicts vocabulary growth in late-talking (LT) infants who are having difficulty in the early stages of language learning.

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Research with TD children has documented substantial individual differences in the rate and shape of vocabulary growth over the second and third years (Huttenlocher, Haight, Bryk, Seltzer & Lyons, 1991). However, few studies have charted longitudinal trajectories of vocabulary growth in children who are slow to begin talking (Rescorla. Mirak & Singh, 2000), as compared to peers with early vocabulary growth in the normal range. Modeling growth over age within individuals is an increasingly popular technique that provides a more sensitive measure of group differences than other analytic methods, revealing a more consistent picture of which factors best predict patterns of catch-up vs. continued delay (Singer & Willett, 2003). Here we use growth curve analysis (GCA) to characterize variation in trajectories of vocabulary development from 18 to 30 months in children with typical- and late-onset vocabulary.

The Significance of Individual Differences in Early Language Learning

Many studies of language acquisition assume that TD children adhere to a rapid and regular course of development over the first few years. Most children show signs of comprehension before their first birthday, producing their first words a few months later. Vocabulary growth continues over several months at a relatively slow pace, accelerating as children begin to produce simple word combinations. While this general characterization is apt for most children, it is also clear that there is substantial variability in the timing of early language milestones. Large-scale studies using parent-report measures like the MacArthur-Bates Communicative Development Inventories (MB-CDI) indicate that this variation is relatively stable across the normal range, at least over the short term (Fenson et al., 2006). Yet with few exceptions (e.g., Bates, Bretherton & Snyder, 1988), the study of individual differences has not been viewed as critical to understanding fundamental mechanisms underlying construction of language by TD children. While patterns of early vocabulary development have been used to characterize different language learning ‘styles’ as dichotomous categories (e.g., ‘referential’ vs. ‘expressive’ [Nelson, 1973]), such differences among children were not considered as evidence of continuous variation along meaningful dimensions of language proficiency.

In contrast, variability in language learning is a central issue in research on language disorders. Children with language impairments have often been viewed as a heterogeneous group, qualitatively different from TD children, a view that is gradually changing. Rather than classifying such children as categorically separate from children in the normal range, many clinical researchers now favor a “dimensional” view in which children with impairments represent the lower end of multiple continuous dimensions of language skills that are normally distributed (Leonard, 1991; Rescorla, 2009). Consistent with this perspective, a review of epidemiological research with a large sample of children varying in language proficiency found “no strong support for a clear distinction between language impairment and normal ranges of language function” (Tomblin, Zhang, Weiss, Catts & Weismer, 2004, p. 72). Although it would be clinically convenient if researchers could provide a “litmus test” for early identification of children with language disorders (i.e., a child either has a disorder or does not), there is increasing appreciation of the complexity of endogenous and exogenous factors that influence developmental trajectories (Bishop, 2006). Groupings based on conventional cut-offs (e.g., > 1 SD below the mean) are applied in clinical practice as well as in research designs exploring clinically relevant variation in language proficiency (e.g., McMurray, Samuelson, Lee & Tomblin, 2010). Here we also use this strategy by including a group of LT children known to be at increased risk for language difficulties. However, the heterogeneity within disorder categories, as well as the many similarities in patterns of variation across children who show normal and delayed development, are now widely acknowledged (Tomblin et al., 2004). While limitations in the skills necessary to learn language, or in the opportunities to develop those skills, place children more or less at risk for persistent delays, these diverse risk factors clearly operate in a probabilistic, rather than an absolute, fashion (Thal & Katich, 1996).

Consistent with the view that language skill varies along multiple continuous dimensions, research on individual differences in adult comprehension is increasingly influential in constraining models of language processing. Studies using behavioral measures of sentence comprehension reveal substantial variation in adult performance (e.g., Dąbrowska & Street, 2006). Adults who score higher in language proficiency also display different patterns of brain responses involved in lexical access (Weber-Fox, Davis & Cuadrado, 2003) and syntactic processing (Pakulak & Neville, 2010), compared to adults with lower proficiency scores. One explanation is that variability on language processing tasks is due to individual differences in fixed cognitive capacities such as working memory (Just & Carpenter, 1992). However, there is growing evidence that differences in comprehension skill are better explained in terms of experience-based factors rather than capacity limits. MacDonald and Christiansen (2002) argue that the tasks used to assess verbal working memory actually measure processing skills strongly correlated with reading proficiency, and thus performance could be influenced by education and experience rather than reflecting inherent limitations in cognitive capacities. Other recent studies have begun to explore potential contributions of experience with language to skill in language processing (e.g., Wells, Christiansen, Race, Acheson & MacDonald, 2009). This perspective highlights the intriguing possibility that individual differences in language proficiency among adults may be continuous with the variation in processing fluency we observe in children early in development, a theme we return to in the Discussion section.

The Difficulties of Predicting Language Outcomes in Late-Talking Children

In this study we ask whether relations between early processing efficiency and vocabulary growth are parallel in two groups of children who fall in different regions on the distribution of productive vocabulary at 18 months. Late talkers are children younger than 3 years who are at the lower-end of the continuum in language production, and who do not exhibit any neurological, sensory or cognitive impairments (Desmarais, Sylvestre, Meyer, Bairati & Rouleau, 2008). Although LT children are most often defined as such at 24 months, the age of identification ranges from 18 months to 3 years. In studies using parent report, late talkers are arbitrarily defined as children who fall at or below the 10th percentile in vocabulary production, although more liberal cut-offs are often used in research studies (Jones, 2003). Note that the label “late talker” does not entail a clinical diagnosis, given that many LT children will “bloom” by moving into the normal range of language skills by kindergarten (e.g., Ellis Weismer, Murray-Branch & Miller, 1994). However, there is mounting evidence that LT children who eventually “catch up” may nevertheless continue to show weaknesses in some language domains in later years, as compared to peers who were never delayed (Rescorla, 2009).

Why do some LT children overcome their early delays while others do not? Dale et al., (2003) concluded that lexical production used as the sole measure of language level has poor practical utility in distinguising transient from persistent delay in children younger than 2 years. Other correlates of persistent language delay have been considered, including maternal education and birth order (Hoff-Ginsberg, 1998). A mediating variable may be the early language environment of the child (Hoff, 2003). Relations between maternal talk and vocabulary outcomes may also be influenced by factors such as maternal literacy levels, depression, knowledge of child development, and parenting practices (Pan, Rowe, Singer & Snow, 2005; Rowe, 2007). Still other predictors such as male gender, family history of language delays, and prematurity are also linked to late onset of productive language at 24 months (e.g., Zubrick, Taylor, Rice & Slegers, 2007). Yet even when these predictors are taken together, they typically account for only a small portion of the variance and are not likely to be useful for early screening of vocabulary delays in children under 2 years (Reilly et al., 2007). Individual differences in early comprehension are also linked to later differences in expressive language. While some studies of LT children have specifically excluded those with comprehension deficits (Fischel, Whitehurst, Caulfield & DeBaryshe, 1989), others show that LT children who have receptive delays are at greater risk for poor outcomes than late talkers with normal-range comprehension (Thal, Tobias & Morrison, 1991; cf. Paul, 1991).

Yet assessing early comprehension in infants and toddlers can be exceedingly challenging. The use of offline behavioral measures requires asking a young child to pay attention, follow instructions and execute an unambiguous response. And since such tasks rely on responses made *after* the offset of the speech stimulus, they do not tap into the real-time properties of spoken language understanding. Although vocabulary inventories provide a practical alternative to face-to-face tasks, concerns have been raised about their reliability and validity for assessing early comprehension (Tomasello & Mervis, 1994). However, recent refinements in experimental techniques using online measures now allow researchers to monitor the time course of language comprehension by young language learners, providing a direct assessment of early efficiency in spoken language processing that is both reliable and ecologically valid (Fernald, Zangl, Portillo & Marchman, 2008).

The Contribution of Early Language Processing Skills to Language Learning

Clinical studies of language delay in school-aged children show that Specific Language Impairment (SLI) is robustly associated with speed and capacity limitations in the processing of phonological, semantic, and grammatical information (Leonard et al., 2007). Delays in LT toddlers and in preschoolers with SLI have also been linked to difficulties in speech processing and word learning (Ellis Weismer & Evans, 2002). However, such studies have mostly relied on offline measures of learning outcomes, rather than assessing children’s efficiency in interpreting spoken language in real time. In TD infants, researchers using habituation or reinforced head-turn procedures have begun to identify links between early speech processing and later language outcomes (Benasich & Tallal, 2002; Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow, 2006). Kuhl and colleagues found associations between infants’ sensitivity to native and non-native phonetic contrasts and later vocabulary development (Kuhl, Conboy, Padden, Nelson & Pruitt, 2005; Tsao et al., 2004). A more recent study showed that infants who displayed differential event related potentials (ERPs) to native vs. non-native contrasts at 7.5 months showed more accelerated vocabulary growth from 14 to 30 months (Kuhl et al., 2008). Other studies using ERPs to assess early lexical-semantic sensitivity also find links to later vocabulary development (Friedrich & Friederici, 2006; 2010)

While these findings with preverbal infants suggest that early speech perception skills are linked to later language development, the tasks used in this research do not assess apprehension of meaning. Research on language processing in the second and third year has used online measures to assess how efficiently children identify the referent of a familiar word in real-time comprehension. In the looking-while-listening (LWL) procedure, children see pictures of two familiar objects as they listen to speech naming one of the objects (Fernald et al., 2008). English- and Spanish-learning infants show dramatic gains in the speed and accuracy of language understanding across the second year (Fernald, Pinto, Swingley, Weinberg & McRoberts, 1998; Hurtado, Marchman & Fernald, 2007). Moreover, young children, like adults, are able to interpret incoming language incrementally, directing their attention to the appropriate picture as the speech signal unfolds in time (e.g., Fernald, Swingley & Pinto, 2001; Swingley, Pinto & Fernald, 1999). In a longitudinal study with TD toddlers from 15 to 24 months, these online processing measures were found to be relatively stable over time, and processing speed at 24 months was robustly correlated with vocabulary growth over this period (Fernald et al., 2006). Moreover, a follow-up study with the same children six years later revealed strong links between processing efficiency in infancy and performance on standardized tests in elementary school, especially those involving working memory (Marchman & Fernald, 2008). Building on these earlier findings, the current longitudinal study examines the predictive validity of real-time language comprehension in TD children and in children identified as late talkers at 18 months.

Goals of the Current Study

Using a prospective longitudinal design, we explore relations between language processing efficiency at 18 months and subsequent vocabulary growth in TD and LT children. The first goal is to chart individual variation in lexical development across four time points from 18 to 30 months. Trajectories of development are described in terms of three parameters: intercept (vocabulary size at 30 months), linear growth (rates of change from 18 to 30 months), and quadratic growth (rates of acceleration from 18 to 30 months). We then compare these parameters in children classified as LT (below the 20th percentile in word production at 18 months) with those of children classified as TD (above the 20th percentile at 18 months). Is the shape of developmental change in vocabulary between 18 and 30 months different for LT and TD children? Do children with late-onset vocabulary at 18 months display trajectories of growth that reflect “catch up”, or do the continue to lag behind TD children at 30 months?

The second goal is to explore how efficiency in language processing at 18 months is related to trajectories of lexical growth over the subsequent year in LT and TD toddlers. Do speed and accuracy of familiar word recognition at 18 months predict variation in rate and acceleration of vocabulary development from 18 to 30 months? And does skill in the efficiency of verbal processing at 18 months differentiate those LT children who move into the normal range in vocabulary over the following year from those who show continued delays?

Method

Participants

Participants were 82 children (41 female), recruited from families with 15- to 17-month-old infants identified through birth records. All parents reported their child was born full term with no perinatal complications, and had experienced no serious illnesses, cognitive delays, or impairments in hearing or vision. Parents were sent a questionnaire asking about demographic information, language use at home, health history, and family history of language disorders. Parents also completed a MacArthur-Bates CDI: Words & Gestures (Fenson et al., 2006). In order to include a substantial number of LT children, special effort was made to recruit children who scored low in vocabulary production as well as comprehension, whose parents reported concern about their child’s language development and/or a family history of language or learning delays. Thirteen children were reported to have an immediate family history of speech or language impairment. Nearly 60% of the children were firstborn, and none had significant exposure to a language other than English. As shown in Table 1, most parents were college educated from an upper middle-class population, with most families in the semi-professional or professional stratum according to the Hollingshead Index of Social Status (Hollingshead, 1975).

Assessing Vocabulary

At 18 months, parents completed the MB-CDI: Words & Sentences. Vocabulary size was the number of words reported to be produced on a checklist of 680 words. Children were grouped as typically-developing (TD, *n* = 46; 25 females) if scores were > 20th percentile. Late talkers (LT, *n* = 36; 16 females) were those with scores ≤ 20th percentile. Of those children with a family history of speech/language impairment, 8 (4 males) were in the TD group, and 5 (2 males) were classified as LT. Maternal education and HI were not reliably different in the TD and LT groups (Table 1). When children were 21, 24 and 30 months, parents again completed MB-CDIs, from which total vocabulary and percentiles by age and gender were derived. For some analyses, children were further subdivided based on percentile scores at 30 months. In the LT group, children whose vocabulary remained ≤20th percentile at 30 months were classified as "delayed" (*n* = 14), while those with vocabulary >20th percentile at that age were classified as "bloomers" (*n* = 22). In the TD group, children were also grouped by vocabulary outcome at 30 months based on a median split, to enable comparison of those in the "lower half" (*n* = 22; <74th percentile) with those in the "upper half" (*n* = 24, ≥74th percentile) of the TD distribution.

Assessing Online Language Understanding

Procedure—Infants' speed and accuracy in recognizing familiar spoken words were assessed at 18 months in the LWL procedure. The child was seated on a caregiver's lap in front of a rear-projection screen. On each trial, children viewed pictures of two familiar objects and listened to speech naming one of the pictures. The two pictures were shown in silence for 2 s, continuing for 3 s during sentence presentation and 1 s after sound offset. Between trials, the screen was blank for 2000 ms. Each trial lasted ca. 7000 ms. The caregiver wore opaque sunglasses during testing to block their view of the images. Children were tested in two 5-min sessions ca. 1 week apart. Prior to the first session, parents indicated on a questionnaire whether or not their child understood each of the target words.

Stimuli—Speech stimuli for each session consisted of 32 simple sentences ending with a familiar target noun (e.g., *Where's the doggy?*), recorded by a female native speaker of English. The eight target nouns were highly familiar to children in this age range (*doggie-baby*, *book-car*, *ball-shoe*, *kitty-bird*). Final stimulus sentences were chosen from multiple tokens based on comparability in target word duration (*M* = 639 ms, range = 565–769). Visual stimuli consisted of pictures of objects corresponding to these nouns. Each object served equally often as target and distracter. Four digitized pictures of tokens matched for visual salience were used for each target object. Side of target picture was counterbalanced across trials.

Coding—Children's gaze patterns were videotaped and later coded frame-by-frame, yielding high-resolution records of eye movements for each 33-msec interval. Trials were later classified as either target-initial or distracter-initial depending on which picture the child was fixating at the onset of the target noun. To determine assess reliability, 25% of the sessions were independently recoded. Inter-observer agreement was computed in two ways: First, the proportion of all frames on which coders agreed on gaze location averaged 98.8%. A second measure determined the mean proportion of shifts in gaze on which coders agreed within one frame. This more conservative measure also yielded high reliability estimates (97.9%).

Measures of processing efficiency—Two measures of efficiency in real-time speech processing were calculated, *accuracy* and *reaction time*. Accuracy was the mean proportion of looking to the named picture on target- and distracter-initial trials 300 – 1800 ms from noun onset, based on *M* = 49.0 trials per participant (range = 22 – 64 trials) across the two sessions. Mean accuracy scores were also computed using only trials for which parents reported the target word as understood by their child, in the few cases where a child was unfamiliar with a target word. This resulted in 3.1 fewer trials/participant for children in the TD group (*M* = 47.1, range = 17 – 63) and 5.6 fewer trials/participant for the LT group (*M* = 41.4, range = 9 – 62).

Mean reaction time (RT) to shift to the correct referent was calculated for each child based on distracter-initial trials on which the child started on the distracter picture and shifted to the target picture within 300 – 1800 ms from target word onset. Those trials on which the child shifted within the first 300 ms or later than 1800 ms from target onset were excluded, since such shifts are less likely to be in response to the stimulus sentence (Fernald et al., 2008). A total of *M* = 19.4 trials/participant (range = 3 – 32) was used to compute mean RT across all children, with *M* = 19.8 (range = 4 – 31) for the TD group and *M* = 18.9 (range = 3 – 32) trials for the LT groups. Mean RT was also computed based only on trials for which parents reported the child understood the target word. These mean RTs were based on a slightly smaller number of trials per child in both groups: TD *M* = 18.8 trials (range = 4 – 31); LT *M* = 17.2 trials (range = 3 – 32).

Results

We first provide descriptive information on vocabulary at each age in TD and LT children. Next, we examine speed and accuracy of online language understanding as a function of language status group (TD and LT) at 18 months, to determine whether children with late-onset vocabulary are less efficient in real-time language comprehension than their TD peers. Finally, growth curve analyses are used to chart the course of lexical development in TD and LT toddlers. We explore group differences in trajectories of vocabulary growth and then assess the predictive validity of language processing efficiency in accounting for individual variation in parameters of vocabulary growth from 18 to 30 months of age.

Vocabulary Outcomes by Group

Table 1 presents vocabulary scores for children in the TD and LT groups. By definition, LT children had significantly lower vocabulary scores than TD children at 18 months. These initial group differences persisted over the following year; LT children had significantly lower scores than TD children at every time point (all $p < .001$) from 18 to 30 months. Within the TD group, the 18- and 30-month vocabulary scores were significantly correlated, indicating moderate stability over this period, $r(46) = .41$, $p < .005$, and more than 91% of TD 18-month-olds remained within the normal range at 30 months. There was also a noteworthy reduction in variance in the TD group at 30 months due to a ceiling effect: nearly half the children scored >600 words, at or near the 680-word limit of the MB-CDI vocabulary instrument.

For LT children, the relation between language group status at 18 and 30 months was less stable, $r(34) = .24$, *ns*. Although 14 of the LT group (39%) continued to show delays at 30 months, 22 LT children (> 60%) made sufficient gains in vocabulary to score within the normal range by 30 months. In other words, of the 18 children who were below the 20th percentile at 30 months and thus were classified as delayed, 14 had also been classified as LT one year earlier, and only 4 of 18 children who were delayed at 30 months had originally been identified as TD at 18 months. Thus, LT children at 18 months were substantially more likely than TD children to show delays at 30 months. This indicates that being classified as a late-talking toddler based on vocabulary size at 18 months has moderate sensitivity (14 of 18, 78%) for predicting a delay one year later. Specificity was also strong (42 of 64, 66%) since most children with TD language at 18 months remained within the normal range at 30 months. Analogously, the absence of an early delay had strong *negative* predictive value (42 of 46, 87.5%), since relatively few children classified as TD fell below the 20th percentile one year later. However, as in previous studies (e.g., Dale et al., 2003), many children with late-onset vocabulary improved over this 12-month period, indicating that LT status at 18 months, considered on its own, has low *positive* predictive value (14 of 36; 39%) as a marker for persistent language delay.

Spoken Language Processing in Late-Talking and Typically-Developing Toddlers

We next explore variation in children's processing efficiency at 18 months, assessing speed and accuracy in online word recognition. Mean RT and accuracy in both language groups are presented in Table 2. Group comparisons indicated that children in the LT group were, on average, significantly slower and less accurate in spoken language understanding than those in the TD group. Moreover, 18-month vocabulary was significantly correlated with concurrent RT, $r(82) = -.32$, $p < .004$, and accuracy, $r(82) = .36$, $p < .001$, across all children.

Although care was taken to select target words highly familiar to children in this age range, 18-month-olds with smaller vocabularies might have been less efficient in online processing simply because they were less familiar with the target words on which they were tested. Thus we also calculated measures of processing efficiency based only on trials with target words that were "reported-understood" by parents. In this analysis, RT and accuracy remained generally unchanged for the TD group, although group differences were less pronounced for the LT group (see Table 2). Nevertheless, the correlations with vocabulary remained reliable for both RT, $r(82) = -.27$, $p < .02$, and accuracy, $r(82) = .36$, $p < .001$. Thus, the links between vocabulary and spoken language processing found here cannot be explained by less efficient children being unfamiliar with the words being tested, consistent with earlier findings (Fernald et al., 2006).

Using GCA to Model Trajectories of Vocabulary Growth

The results so far indicate that late-onset vocabulary at 18 months predicted continued language delay, and that LT children were slower and less accurate than TD children in online language understanding when tested on highly familiar words at 18 months. But we have not yet taken advantage of the *longitudinal* nature of our data to explore trajectories of vocabulary growth *within individuals* across this important period. Growth curve analysis (GCA) employs a type of multi-level model of change in which measurements repeated at each time point are grouped within each individual (Singer & Willett, 2003). To examine the shape of those measurements over time, the first step is to model individual trajectories of growth for all children from 18 to 30 months. In these Level 1 (or unconditional) models, repeated observations of individuals are assessed with respect to individualized growth functions described by a unique set of parameters (e.g., *intercept* and linear rate of change, or *slope*). Because vocabulary was assessed at four points, it was also possible to explore the degree to which individual trajectories were characterized by gradual increases or decreases in rate of change (i.e., *acceleration* or *deceleration*). These models provide descriptive information regarding the nature of developmental change in vocabulary that is characteristic of the sample on average, as well the degree to which individuals vary in each of the parameters. Next, the Level 2 models explore whether factors that systematically vary between individuals can account for individual differences in growth parameters. Specifically, we evaluated whether initial language status group (LT vs. TD) and efficiency in online language processing (RT and accuracy) at 18 months accounted for variation in 30-month outcomes and vocabulary growth from 18 to 30 months.

At Level 1, the average trajectory of vocabulary development was modeled across individuals in terms of three parameters: (a) intercept (vocabulary: 30 months), (b) rate of change (linear change: 18–30 months) and (c) acceleration/deceleration (quadratic change: 18–30 months). By setting the intercept at 30 months, we could explore predictors of variation in vocabulary *outcome*, as well as in *shape of change*. All models used the mixed procedure in SPSS (Version 16.0), with maximum likelihood estimation and an unstructured covariance matrix. Results are summarized in terms of overall model fits (goodness of fit expressed as −2 Log Likelihood [−2LL] in “smaller-is-better” form), number of parameters, estimates of coefficients for fixed effects, and covariance estimates for random effects. In the Level 2 models, fixed effects ascertain whether the predictors account for individual differences in each of the growth terms. The random effects assess amount of outcome variability left unexplained in the model. As predictors are added, their impact can be evaluated in terms of how much additional variance is accounted for, i.e., the proportional reduction in unexplained variance, compared to a simpler model.

Following guidelines in Singer & Willett (2003), an unconditional means model was our starting point. Model 1 in Table 3 estimated a mean reported vocabulary of 263.1 words averaged across all individuals and time points. Note that introducing the linear term (Model 2) yielded a significantly better fit to the data than the unconditional model since the difference in fit statistics ($\Delta -2LL = 4397.9 - 3958.5 = 439.4$) exceeded the critical value of 13.82 ($p < .001$) for a χ^2 distribution with 3 degrees of freedom (i.e., the difference in the number of parameters in Model 2 vs. Model 1). However, a quadratic model (Model 3) provided the best fit overall, yielding a significantly better fit than the unconditional model ($\Delta -2LL = 574.3 > \chi^2(df = 7) = 24.32$, $p < .001$) and the linear-only model ($\Delta -2LL = 134.9 > \chi^2(df = 4) = 18.47$, $p < .001$.

In Model 2, parameter estimates for the fixed effects revealed that children’s vocabulary size increased by 35 words per month, on average, reaching more than 500 words at intercept, i.e., at 30 months. The quadratic fixed effect was not reliable, indicating that average rate of acceleration/deceleration in vocabulary growth across all children was not significantly different from zero. However, inspection of the random effects revealed significant unexplained variance in all terms. We now turn to conditional models which evaluated the power of our Level 2 predictors to account for individual variation in these outcome and growth parameters.

Vocabulary growth as a function of language status group—Three conditional growth models (Level 2) are presented in Table 4. In Model 4, including language group (LT, TD) in our conditional quadratic model improved overall model fit compared to the unconditional quadratic model, Model 3 ($\Delta -2LL = 60.3 > \chi2(3) = 16.27$, $p < .001$). In addition, one can evaluate the impact of each predictor on model fit in terms of a pseudo $R^2{}_e$ statistic that reflects the reduction in residual variance from the unconditional to the conditional model. To illustrate, the decline in residual variance in intercept from Model 3 to Model 4 was 5416.4 (22872.7 – 17456.3). This represents a 23.7% decrease in the amount of variance in the intercept left *unexplained* by the model (5416.4/22872.7 = .237) when group was included as a Level 2 predictor. Analogously, including language group in the model reduced the unexplained variance by 29.2% for the linear parameter, and 35.1% for the quadratic parameter, compared to the unconditional model (Model 3). Thus, TD vs. LT status at 18 months accounts for a substantial amount of the individual variation observed in children’s predicted trajectories of vocabulary growth.

We can illustrate these effects by plotting parameter estimates in terms of the average fitted growth trajectory for children in the TD vs. LT groups. As seen in Figure 1, the trajectory of growth for the average LT child lags about 6 months behind that of the average TD child, showing acceleration in rate of growth after vocabulary size reached ca. 100 words. More specifically, the average TD child produced about 148 more words than the average LT child at 30 months, shown by the language group×intercept fixed effect. Moreover, the average TD child gained nearly 36 fewer words/month (language group×linear) and showed a significantly more negative quadratic trajectory (language group×quadratic) than the average LT child. In general, the fitted trajectory of growth for the LT group had a steeper, more positive curvature, characterized by a slower rate of change early in the period and more rapid change later on. In contrast, the average trajectory for the TD children showed early moderate increases in growth rates followed by a slowing, or deceleration, in rate of change. However, note that since many TD children scored near the upper limit of the MB-CDI measure, this negative curvature is due to ceiling effects rather than to an actual decline in rates of vocabulary growth.

To summarize so far, the growth curve analyses revealed that LT children exhibited trajectories of vocabulary learning that landed them behind their TD peers, on average, with significant delays persisting at least to 30 months. But LT children also displayed rapid and accelerating gains in vocabulary over this period, since many, but not all, LT children moved into the normal range by 30 months.

Processing efficiency as a predictor of vocabulary growth—The question of central interest in this study was whether speed and accuracy in the LWL task at 18 months could account for individual differences in vocabulary growth in LT and TD toddlers. In a series of conditional growth models summarized in Table 4, we included language status group and RT (Model 5) and language status group and Accuracy (Model 6) as Level 2 predictors. All models used mean RT and accuracy on word-understood trials. Models conducted with all trials revealed an identical pattern of results, but are not reported here. Since our focus was on whether speed and accuracy of spoken language processing accounted for variation in vocabulary in *both* LT and TD children, we compared the parameter estimates and the change in covariance estimates in Models 5 and 6 to the language-group-only model, Model 4. Does skill in language processing at 18 months, assessed in terms of RT and accuracy, account for significant additional individual variation in vocabulary growth beyond TD vs. LT status?

Model 5 (Table 4) revealed that including mean RT significantly improved overall model fit compared to the language-group-only model (Model 4) ($\Delta -2LL = 19.3 > \chi^2(6) = 16.81$, $p < .01$). Moreover, an inspection of the random effects showed that including RT substantively improved the amount of variance explained. Specifically, RT reduced the unexplained variance by 12.7% for intercept, 8.1% for linear growth, and 4% for quadratic growth, compared to the language-group-only model. The parameter estimates also revealed language group×linear, language group×quadratic, RT×intercept and RT×language group×linear fixed effects.

To aid in the interpretation of these findings, Figure 2 plots the average trajectories for children in the TD vs. LT groups, each at two values of “faster” vs. “slower” RTs on word-understood trials at 18 months. These values represent mean RTs that are −1 SD (“faster,” 636.9 ms) and +1 SD (“slower,” 986.7 ms) than the mean (see Table 2), computed across all children. In Figure 2, significant language group×linear and language group×quadratic effects indicate that language group remains a significant predictor, even after RT is added to the model. As in Model 4, LT children showed more rapid and more accelerating change than TD children, who showed less steep and decelerating rates of growth. Of note, though, is the contribution of RT, controlling for language group. The significant RT×intercept fixed effect reveals that children with faster RTs at 18 months had better outcomes at 30 months than did children with slower RTs. However, the RT×language group×linear interaction suggests that the impact of RT on rates of change was different in the TD and LT groups. As shown in Figure 2, those LT children with faster RTs followed steeper trajectories of growth than those with slower RTs, whereas TD children with faster RTs were more likely to hit ceiling, and hence demonstrated slower rates of change than TD children with slower RTs. Thus, speed of spoken language understanding predicted trajectories of vocabulary growth in both LT and TD children.

Model 6 in Table 4 incorporated language group and mean accuracy on known words at 18 months as Level 2 predictors. Including accuracy significantly improved model fit ($\Delta -2LL = 34.3 > \chi^2 6) = 22.46$, $p < .001$). Moreover, including accuracy in the model increased the variance accounted for by 17.4% for intercept, 15.8% for slope, and 14% for acceleration, compared to Model 4. The fixed effects again indicated that language group remained a significant predictor, even when accuracy was added to the model. However, controlling for language group, children with higher mean accuracy scores at 18 months had larger vocabularies at 30 months than children with lower mean accuracy scores. These results are plotted in Figure 3 as fitted average trajectories for TD (dark lines) vs. LT (grey lines) children at two values of mean accuracy on known words at 18 months: “more accurate” (solid lines, +1 *SD*, .73) vs. “less accurate” (dashed lines, −1 *SD*, .55) based on word-understood trials across all children (see Table 2). As with RT, LT children who were more accurate in real-time spoken language understanding learned vocabulary at significantly faster and more accelerated rates, and demonstrated greater catch up, as compared to LT children who were less accurate in the LWL task at 18 months. For TD children, higher accuracy was associated with stronger ceiling effects and decelerating rates of change, as compared to TD children with lower accuracy.

To further illustrate relations between language processing efficiency and vocabulary in LT and TD children, we examined performance in the LWL task at 18 months in sub-groups of children classified by vocabulary percentiles at 30 months. Figure 4a plots the time course of online word recognition at 18 months in the 14 LT children who remained delayed at 30 months compared to their 22 LT peers who were “late bloomers.” This figure shows the mean proportion looking to the named target picture at each 33-ms interval for those trials on which children were fixating the distracter picture at target noun onset. Note that the average time course of shifting from distracter to target is steeper and reaches a higher asymptote in those children who bloomed, as compared to those LT children with persistent delays. This speed advantage for bloomers is also reflected in mean RT scores at 18 months. LTs who bloomed by 30 months were those who had been significantly faster to initiate a shift at 18 months ($M = 785$ ms, $SD = 144$), as compared to LT children who stayed delayed at 30 months ($M = 940$, $SD = 229$), $t(34) = 2.5$, $p < .02$, $d = .96$. Overall accuracy of target looking at 18 months , collapsing across both distracter- and target-initial trials, was also significantly higher in the bloomers ($M = .66$, $SD = .09$) than in the delayed LT group ($M = .57$, $SD = .10$), $t(34) = 2.8$, $p < .009$, $d = .95$.

These findings suggest that less efficient real-time speech processing by LT children at 18 months is associated with increased risk for poor language outcomes at 30 months, compared to LT children with more efficient processing skills. Of the 18 children who remained delayed at 30 months, 11 were LTs who also had mean RTs in the lower-half of the distribution for all children. Even with this liberal cut-off for clustering children as “slower” vs. “faster”, these results yielded moderate sensitivity (61%) in predicting 30-month delays based on a combination of LT status and processing speed. However, note that 9 LT children who were relatively slower to process speech at 18 months showed gains in vocabulary by 30 months. Thus, the combination of slow RT and late-onset vocabulary clearly does not guarantee lower vocabulary size at 30 months. Nevertheless, taking RT into account increased the positive predictive value to 55% (11 of 20), compared to 39% when low vocabulary was considered alone. We also conducted a parallel analysis when children were 24 months old, the age when LT children are most commonly identified. Positive predictive value increased further (8 of 12, 66%) when processing speed and vocabulary status at 24 months were used as predictors. Looking next at accuracy, 10 of the 18 children with persistent delays at 30 months were also LTs at 18 months who had accuracy scores in the lower half of the distribution for all children. Thus, less accurate online comprehension in addition to late-onset vocabulary yields a sensitivity of 55% and an increase in positive predictive value (10 of 19, 52%), compared to LT status on its own. Again, these values improve even more if estimates are based on data from 24 months, rather than 18 months (positive predictive value: 60%).

Within the TD group, we found analogous differences in speed and accuracy of online language processing at 18 months as a function of later vocabulary outcomes. To illustrate, Figure 4b plots the time course of looking to the target picture on distracter-initial trials for the sub-group of TD children who scored in the upper half (n = 24) vs. the lower half (n = 22) of the vocabulary distribution at 30 months. Differences in slopes and asymptotes in the two curves also reflect the fact that those TD children with larger vocabularies shifted significantly more quickly to the named target picture (M = 737, SD = 130), on average, than did children with smaller vocabularies at 30 months (M = 835, SD = 166), $t(44) = 2.4$, $p < .03$, $d = .71$. Mean overall accuracy was also significantly higher in the upper-half group of TD children (M = .69, SD = .07) than in the lower-half group (M = .63, SD = .08), $t(44) = 2.9$, $p < .01$, $d = .87$.

In sum, these analyses reveal strong relations between early efficiency in real-time language interpretation and individual differences in lexical development in children with typically developing and late-onset vocabulary. In infants at all language levels, faster and more accurate recognition of familiar words at 18 months predicted their trajectories of vocabulary growth as well as language outcomes one year later.

Discussion

This prospective longitudinal study provides new evidence that individual differences in infants' efficiency in real-time language comprehension predict vocabulary growth from 18 to 30 months. These findings reveal robust associations between language processing skills at 18 months and lexical development over the following year, both in typically developing infants and in late-talkers at risk for persistent language delays. The first goal was to chart patterns of variation in trajectories of vocabulary growth from 18 to 30 months in TD and LT children. The second goal was to explore the predictive validity of early efficiency in language understanding using online measures of speech processing. Across all children, skill in interpreting familiar words in real time was linked not only to concurrent vocabulary size, but also to rate and shape of lexical growth over the 2nd and 3rd years, above and beyond initial language status group.

Establishing the Predictive Validity of Infants' Skill in Real-Time Speech Processing

This study extends previous research in three important ways. First, our results converge with those of the Fernald et al. (2006) study, which showed that speed and accuracy of language processing at 25 months predicted growth in vocabulary from 12 to 25 months, findings based on a "retrospective" prediction. In a larger and more diverse sample, we have now shown *prospectively* that processing efficiency at 18 months predicts vocabulary growth over the following year. Thus, skill in language comprehension relates to vocabulary learning at an even younger age. In the earlier study, infants participated in a single session of the LWL task at each age, and correlations to offline measures of vocabulary were weaker at younger ages. In the current study, in contrast, 18-month-olds were assessed in two longer sessions of the LWL task, yielding much more data per child. This shows that meaningful individual differences in the efficiency of familiar word recognition are evident at ages younger than 2 years, if appropriate steps are taken to increase the stability and robustness of experimental measures of infants' real-time interpretation of spoken language (see Fernald et al., 2008).

Second, this is the first investigation to use online processing measures with a large sample of infants delayed in onset of speech production, many of whom remained delayed at 30 months. Growth curve analyses revealed that although LT children had smaller vocabularies than TD peers at 30 months, they also showed faster and more accelerated rates of vocabulary growth from 18 to 30 months. A positively accelerating trajectory reflected the fact that nearly two thirds of the children with early delays made greater-than-average gains in vocabulary around their 2nd birthdays. It is precisely this leap in vocabulary growth exhibited by many, but not all, late talkers that weakens the positive predictive value of measures of early lexical production in relation to language outcomes over the longer term (Feldman et al., 2005).

We also discovered that those LT children who were more efficient in word recognition at 18 months were those had more accelerated rates of vocabulary growth over the following year, whereas LT children with less efficient processing showed slower growth and poorer outcomes. In the GCA models, RT and accuracy accounted for 4 to 17% additional variance beyond LT status in predicting vocabulary growth trajectories. Moreover, categorizing LT children in terms of LWL performance substantially improved our ability to predict persistent delays, compared to grouping based on vocabulary size alone. Taken together, these results offer compelling evidence that estimates of speech processing efficiency at 18 months can improve the ability to differentiate those LT children who will move into the normal range from those who will show continued delays. Because low performance in the LWL task at 18 months tended to over-, rather than under-, estimate poor outcomes, our ongoing research is exploring which cut-offs of "poor" performance in the LWL task will maximize positive predictive values. Although it is not yet known which of these children, if any, will later meet clinical criteria for language delay, we are tracking long-term outcomes to determine the effectiveness of early processing efficiency as a marker for subsequent clinical-range language deficits during preschool.

Third, these findings are the first to reveal *comparable* links between early processing efficiency and language growth in two groups of children defined by conventional criteria as "typically-developing" and "late talkers". Speech processing efficiency predicted vocabulary growth from 18 to 30 months across all children, distinguishing those with higher vs. lower outcomes in *both* TD and LT groups. Although the demonstration that early processing efficiency differentiates those LT children who catch up from those who remain at risk has important clinical implications, note that the influence of language processing was *parallel* in TD and LT children. This suggests that correlations between processing efficiency and language growth reported in earlier studies that included only TD children (e.g., Fernald et al., 2006) were not an artifact of the performance of a few children at the low end of the continuum.

The use of GCA required repeated administrations of the same vocabulary measure, the MacArthur-Bates CDI. Although this instrument captured individual differences in both language groups, one limitation of this study is that the CDI was susceptible to ceiling effects for more advanced TD participants. LT children who were faster and more accurate in word recognition at 18 months showed steeper and more accelerated vocabulary growth from 18 to 30 months, compared to those LT children less efficient in verbal processing, who showed slower and more protracted growth. In contrast, TD children with stronger processing skills appeared to have slower growth rates over this period because of ceiling effects due to the limited range of the CDI. Although such divergent patterns seem counterintuitive, we interpret these results as a positive sign of growth for both groups. However, establishing links between early processing efficiency and language outcomes at older ages requires the use of more sensitive outcome measures. In a follow-up to the Fernald et al. (2006) longitudinal study, we found that processing efficiency at 24 months predicted performance on comprehensive standardized assessments at 8 years, most notably those involving working memory (Marchman & Fernald, 2008). Ongoing analyses of data from the current longitudinal sample also reveal promising links between processing measures at 18 months and assessments of receptive and expressive language, non-verbal cognition, and working memory, at 3 and 5 years of age.

Why Faster and More Efficient Processing in Infancy is Advantageous for Language Learning

To understand the implications of these predictive relations, we need to address three questions about developmental processes on different time scales: First, what kinds of skills are captured by our experimental measures of online word recognition at 18 months, and how are they relevant to language processing in more natural situations? Second, how could an advantage in processing efficiency facilitate growth in children's vocabulary in the early years? And third, do the individual differences we observe in infants' real-time processing skills have long-term consequences for language and cognitive development?

First we consider whether our online processing measures capture differences among children in abilities specifically related to language, or whether the task demands of the LWL procedure draw on abilities not unique to speech processing. An infant who quickly and consistently orients to the named picture in this paradigm clearly demonstrates skill in understanding language, but this capacity builds on many perceptual, cognitive, and motor processes not exclusively linked to language. On every trial the infant has to identify the visual image, segment and interpret words in the sentence, and determine whether the object name matches the currently fixated picture. If the target word is a good fit, the correct response is to continue fixating that picture; if there is a mismatch, the correct response is to search for an appropriate referent. In either case, accuracy requires a range of cognitive capabilities such as selective attention, encoding of visual images, integration of auditory/visual information, memory for familiar sound forms, association of the object with the target word, and ability to disengage from the distracter to shift to the target picture. These and other fundamental information processing skills could all influence performance, and none is specific to language. Thus, one interpretation of the relations we found between online processing efficiency and vocabulary growth is that faster response latencies and greater accuracy at 18 months reflect a range of abilities that enable but are not limited to language processing. Differences among children in any these component processes could contribute to different profiles of language proficiency, consistent with the dimensional view of language disorders mentioned earlier (Rescorla, 2009).

Although this study cannot assess contributions of particular cognitive mechanisms to success in the LWL task, such underlying abilities are relevant to children's real-time language processing more broadly. In real-world situations in which children learn new vocabulary, the challenge of linking sound forms with objects requires attention to potential referents, along with skill in parsing the speech stream, categorizing objects, and integrating multimodal information in memory. Thus the cognitive processes involved in interpreting language in the LWL task are essential to infants' comprehension in daily interactions, when caregivers often focus on objects present in the immediate environment. However, the most compelling evidence for the ecological validity of the processing measures in this research is that they correlate consistently with other measures that tap into quite different aspects of children's developing receptive and expressive skill in using language. The concurrent and predictive relations between early processing efficiency and more traditional measures of vocabulary knowledge that emerged in this study have also been found in earlier research with children at different ages (Fernald et al., 2006; Marchman & Fernald, 2008) and across different languages (Hurtado et al., 2007).

The second question relates to a broader time frame, asking how skills that contribute to reliable word recognition at 18 months facilitate early vocabulary learning and grammatical development. Studies with adults show that faster reaction time can free additional cognitive resources (e.g., Salthouse, 1996), a benefit of particular value in early stages of language learning. The infant who identifies familiar words more quickly has more resources available for attending to subsequent words, with advantages for learning new words later in the sentence, as well as for tracking distributional information about relations among words. Children rely increasingly on familiar words to infer meanings of unfamiliar words (Goodman, McDonough & Brown, 1998) and thus must attend to individual words in the unfolding sentence. But they must also remember and relate nonadjacent words, to appreciate long-range dependencies crucial for mastering syntax. A slight initial edge in the efficiency of familiar word recognition could be strengthened through positive-feedback processes, leading to faster growth in vocabulary and grammar that in turn lead to further increases in receptive language competence. Thus there are cascading advantages for infants who know more words and have more efficient processing skills by the age of 18 months, as rapid lexical access of familiar words in real-time processing continues to facilitate further vocabulary growth and grammatical learning.

It is also well known that older children with language delays are slower and less efficient in spoken language processing than TD peers (Montgomery, 2002), a liability that underlies some of the difficulties they experience in word learning and comprehension. Being slow to identify the referent of a familiar word could interfere with lexical activation and impede success in tracking distributional regularities and managing attentional resources in real time (Evans, Saffran & Robe-Torres, 2009). These difficulties would also have implications for the ability to recruit existing lexical knowledge in the service of learning new words (Gershkoff-Stowe & Hahn, 2007), which could contribute to the links between reduced processing efficiency and slower vocabulary growth observed in those LT children who remained delayed at 30 months.

The third question about advantages of efficiency in early comprehension takes a longer view, asking how variability in infants' real-time processing skills could have consequences for language and cognitive development in later years. It is interesting to note that speed of processing and vocabulary size are among the strongest predictors of adult IQ (e.g., Sternberg, 1984). Our findings show that individual differences in these capacities are already evident in infancy and are consistently interrelated. There is ample evidence that variability in both processing speed and vocabulary could have cascading consequences for long-term outcomes. Research with children and adults across a range of linguistic and non-linguistic tasks showed that mean RT at every age predicted success on cognitive tasks (Kail & Salthouse,1994). In fact, RT in adults correlates so robustly with measures of fluid intelligence, memory, reasoning, and language that many researchers believe gradual increases in processing speed can account fundamentally for age-related growth in cognitive and language functioning (Salthouse, 1996). Fry and Hale (1996) explain this association in terms of a developmental cascade, proposing that age-related increases in processing speed serve to strengthen working memory, and that improvements in working memory then lead to greater cognitive competence. Vocabulary size is also a highly reliable predictor of overall IQ in both adults (Matarazzo, 1972) and children (Vance, West & Kutsick, 1989), and an early advantage in this domain can have cascading benefits as well. Correlations between infants' early vocabulary and their progress in grammar led Bates and colleagues to conclude that lexical learning is fundamental for continued linguistic and cognitive development (Bates et al., 1988). Vocabulary knowledge also serves as a building block for later reading development (Lonigan, Burgess & Anthony, 2000). And looking even further ahead, language function in the preschool years is ultimately predictive of high school drop-out or graduation (Alexander, Entwisle & Horsey, 1997).

Although the current study cannot address this question directly, our findings here and in previous longitudinal research are consistent with a model of cascading relations between early efficiency in speech processing speed and increased vocabulary knowledge. Most children make impressive gains in spoken language processing as their rate of vocabulary learning begins to increase over the second and third years. Some 18-month-olds are faster and more reliable in lexical access than others, and those children with more efficient processing skills at this age are able to learn new words more quickly over the following year. The individual differences in processing speed we observed across TD and LT children may have contributed to differential gains in working memory, which in turn affected trajectories of vocabulary growth, as the Fry and Hale (1996) cascade model would suggest. This interpretation is plausible, given our earlier finding that those children who were both faster in processing speed and had larger vocabularies at 25 months were also those with the highest working memory scores at 8 years of age (Marchman & Fernald, 2008). These factors may operate synergistically: If faster lexical access enables more efficient learning of new lexical forms, this could lead to further gains in processing efficiency as well as improvements in working memory, with long term benefits for language and cognition.

Where Do Individual Differences In Early Language Learning Come From?

Having considered some possible consequences of differences among children in early processing efficiency and vocabulary learning, we next ask what is known about the causes of such differences. Language disorders such as SLI are more concentrated in some families than others, and numerous studies have explored possible genetic bases for variation in linguistic proficiency. However, heritability estimates for SLI have been inconsistent, suggesting that language impairments have multiple causes (Bishop, 2006). Recent research also shows that genetic factors account for individual differences in the speech of typically-developing children as well as those with SLI (Hayiou-Thomas, 2008), consistent with the view that children vary in language proficiency along multiple continuous dimensions.

Although it is increasingly evident that cognitive potential is influenced by a multitude of genetic and other endogenous factors, it is also becoming clear that the contributions of early experience to differences in cognitive and language proficiency are substantial. A study of predictors of language problems in monozygotic and dizygotic twins found that shared environmental factors were much more powerful than genetic factors in accounting for similarities in language development between twins in the same family (Oliver, Dale & Plomin, 2004). Other evidence shows that the influence of environmental factors on differences in IQ has often been underestimated in behavioral genetics studies, which tend to focus on twins and adopted children growing up in families relatively high in socioeconomic status (SES). Because the resources and support available to children in high-SES families are typically more abundant and less variable than in low-SES families, effects of family environment on cognitive and language development are nonlinear (Rowe, Jacobson & Van den Oord, 1999; Turkheimer, Haley, Waldron, D’Onofrio & Gottesman, 2003). Assuming that children have a range of potential cognitive abilities that will develop optimally given adequate environmental support, children in impoverished families are less likely to develop optimally and achieve their full potential. However, in families where resources are abundant, children will be more likely to reach their potential, and differences among them would then appear to be largely due to genetics. In a diverse sample of 7-year-old twins, Turkheimer et al. (2003) found that SES modified the heritability of IQ. Among children living in poverty, 60% of the variance was accounted for by shared environmental factors, with the genetic contribution close to zero; however, for children in higher-SES families, the opposite pattern of findings emerged.

Consistent with this picture, detailed longitudinal studies have shown that parent-child interaction varies substantially among families, and that differences in the amount and quality of child-directed speech predict developmental outcomes such as vocabulary growth (e.g., Huttenlocher et al., 1991). Hart and Risley (1995) found that by 36 months, higher-SES children knew twice as many words as lower-SES children. But the most striking finding was the extent of variation among families in the amount of speech directed to the child in the early years, which was predictive of children's academic achievement years later (Walker, Greenwood, Hart & Carta, 1994). Hoff (2003) has shown that the well-established relation between SES and children's vocabulary knowledge is actually mediated by differences among mothers in the lexical diversity and grammatical complexity of their speech to children in the early years.

Could variation in early language experience also contribute to the individual differences observed in this and earlier studies of infants' real-time processing efficiency and vocabulary growth? Hurtado, Marchman and Fernald (2008) explored this question in longitudinal research with Spanish-speaking mothers and infants, examining links between maternal talk and children's processing efficiency and lexical development. Even within this primarily low-SES sample, there was substantial variation among families in amount and diversity of child-directed speech. As expected, those infants whose mothers had talked with them more during a play session at 18 months were those who learned more vocabulary by 24 months. But the most noteworthy finding was that those infants who had experienced more and richer language were also faster in lexical access 6 months later than those who had heard less maternal talk, controlling for RT differences at 18 months. The opportunity for engagement with rich and varied language from an attentive caretaker provides the infant with models for language learning and also with valuable practice in interpreting language in real time. These results suggest that experience with child-directed talk not only enables faster learning of new vocabulary – it also sharpens the processing skills used in online comprehension.

We cannot distinguish among endogenous and experiential factors that may have contributed to the individual differences among the TD and LT children observed in the present study, and in considering evidence for the crucial role of early experience in language development, we are certainly not denying that biologically-mediated differences in the potential for verbal proficiency are an important source of phenotypic variation among children. Rather, our goal is to call attention to alternative explanations for the individual differences both in early processing efficiency and in lexical development, and the consistent relations between these two dimensions of language skill, that we have observed in this study and in earlier longitudinal research (Fernald et al., 2006; Marchman & Fernald, 2008).

Conclusion

The majority of studies on early language learning have focused on characterizing modal patterns of developmental change in children's linguistic proficiency, with much less attention to the differences among individuals that are also characteristic of children at every age. In this prospective longitudinal study, we documented variation in vocabulary growth across the 2nd and 3rd years in TD and LT toddlers, exploring individual differences in lexical development in children across a broad range of early language skills. We found that speed and accuracy of real-time spoken language processing at 18 months predicted subsequent vocabulary development in comparable ways for children in the normal range as well as for those falling at the low end of the vocabulary distribution. One promising implication of this research is that time course measures of comprehension in very young language learners could ultimately prove useful in improving early identification of children at risk for persistent language disorders.

These findings resonate more broadly with emerging perspectives in other areas of research on language. As in most developmental studies, studies of adult language processing have also focused primarily on ‘modal performance’, with less attention to variation. The few early studies that examined individual differences in adults’ success in sentence processing (e.g., Just & Carpenter, 1992) tended to emphasize fixed capacity limits in working memory as the source of these differences, without considering experience-based explanations. However, interest in variation among adults in language processing skill is steadily increasing. Several recent studies show that adults vary substantially and on multiple dimensions in their ability to interpret complex sentences in real time, and that differences in language experience contribute to such variability in performance (e.g., MacDonald & Christiansen, 2002; Wells et al., 2009). An intriguing implication of our results is that the early links we have discovered between variation in processing efficiency and vocabulary growth in TD and LT children may be continuous with differences in processing skill and language attainment observed in older children and adults. Such developmental continuity would also be consistent with dimensional accounts of variation in language-based skills that are emerging in research on language disorders (Leonard, 1991; McMurray et al., 2010; Rescorla, 2009). Individual differences in language-related abilities are evident as early as these abilities can be assessed in infancy. Studying the emergence of variability in language processing skill and facility in vocabulary building in diverse groups of children over time will enable us to understand more deeply where these early differences come from and how they are linked to linguistic proficiency at later ages.

Acknowledgments

This research was supported by grants from the National Institutes of Health (HD42235 and DC008838). We are also grateful to the children and parents who participated in this study. Special thanks to Nereyda Hurtado, Ana Luz Portillo, Poornima Bhat, Christine Potter, Amber MacMillan, Grace Budde, Adriana Weisleder, Christina Branom, Rebecca Wedel, Renate Zangl, and the staff of the Center for Infant Studies at Stanford University.

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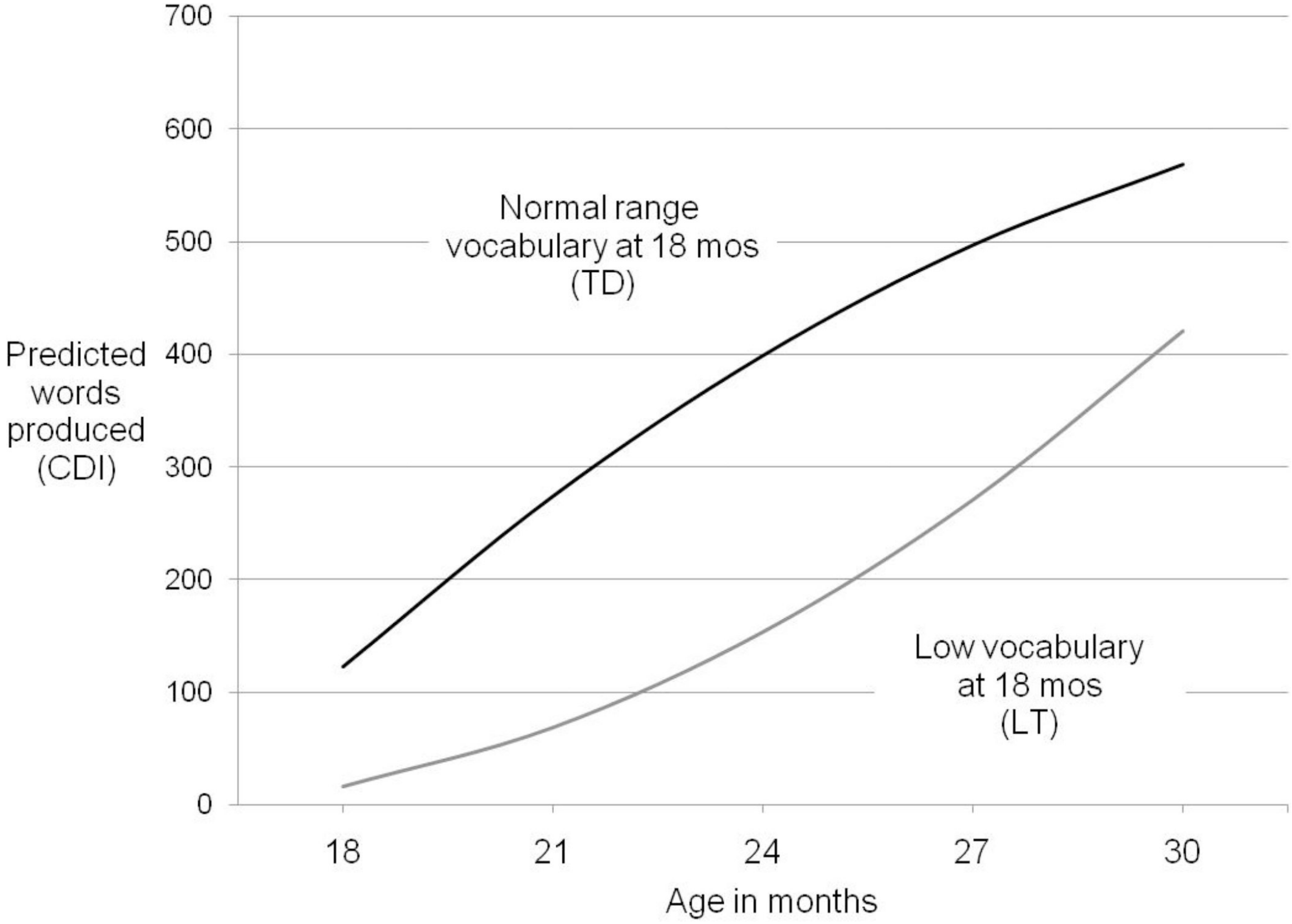

Figure 1.
Predicted mean trajectories of quadratic growth in vocabulary from 18 to 30 months for children in the TD (dark line) and LT (grey line) groups.

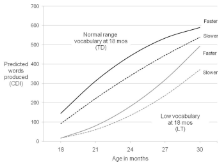

Figure 2.
Predicted mean trajectories of quadratic growth in vocabulary from 18 to 30 months as a function of TD (dark lines) and LT (grey lines) group and faster (+1 SD, solid lines) vs. slower (−1 SD, dashed lines) mean RTs at 18 months.

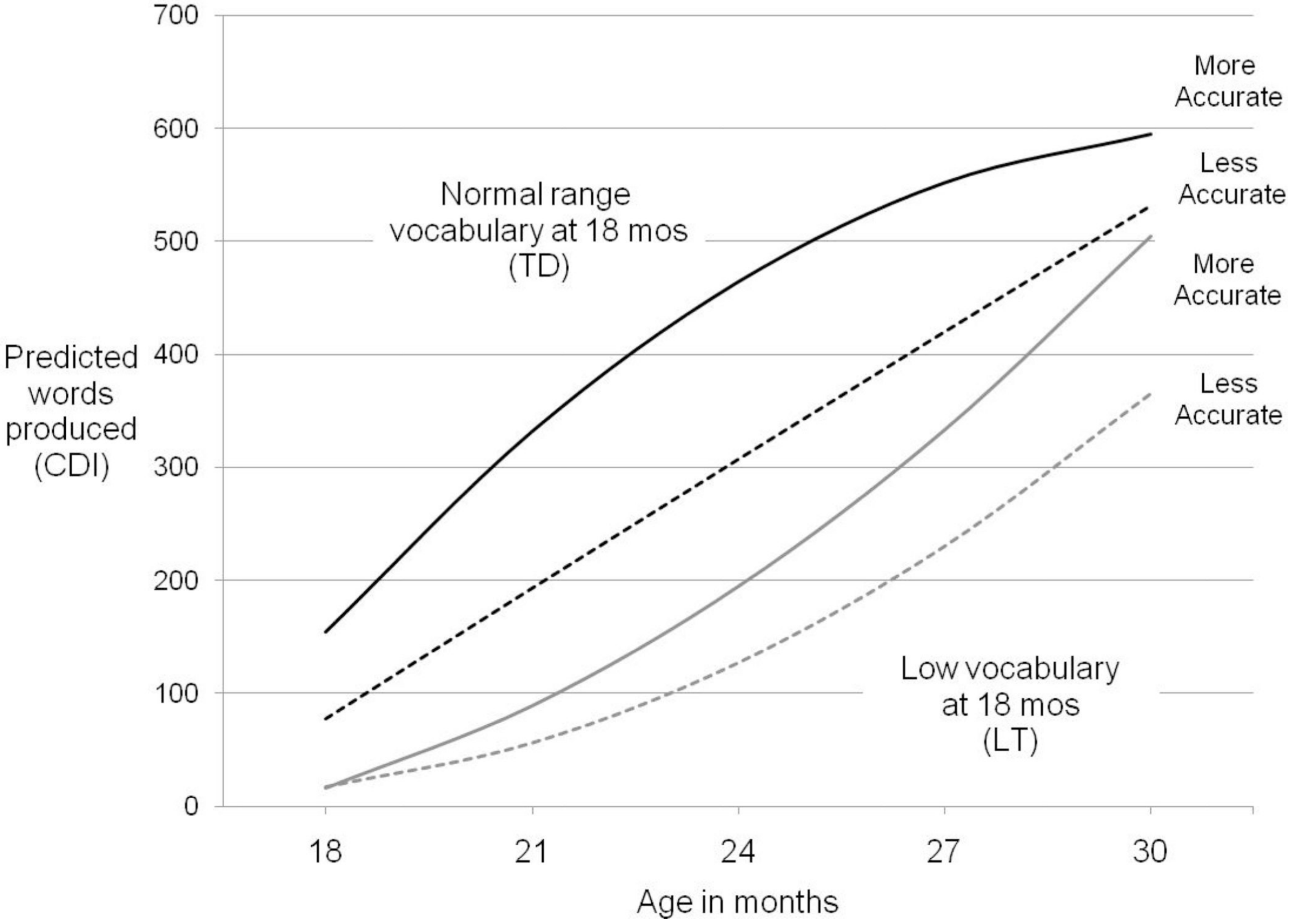

Figure 3.

Predicted mean trajectories of quadratic growth in vocabulary from 18 to 30 months as a function of TD (dark lines) and LT (grey lines) group and higher (+1 SD, solid lines) or lower (−1 SD, dashed lines) mean accuracy scores at 18 months.

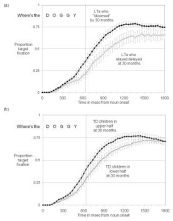

Figure 4.
Time course of the mean proportion fixating the target picture on distracter-initial trials at 18 months as a function of vocabulary outcomes at 30 months. (a) LTs who bloomed vs. those who remained delayed at 30 months; (b) TDs who fell in the high-normal vs. low-normal range at 30 months. Error bars represent SEs of the mean.

Table 1

Mean (SD) of SES variables and reported vocabulary in typically-developing (TD) and late-talking children (LT)

	Full Sample (*n*=82)	**Language Group[a]**		
		TD (*n*=46)	**LT (*n*=36)**	***t*(80)**
Maternal ed (yrs)	16.6 (1.3)	16.5 (1.3)	16.7 (1.3)	0.58, *ns*, *d* = 0.1
Hollingshead[b]	58.4 (8.5)	59.0 (8.1)	57.6 (9.1)	0.77, *ns.*, *d* = 0.2
Vocabulary (raw)[c]				
18 mos	76.7 (76.0)	121.1 (73.3)	20.0 (15.7)	7.9, $p < .001$, $d = 1.9$
21 mos	183.2 (153.7)	277.5 (140.3)	62.0 (50.3)	8.7, $p < .001$, $d = 2.0$
24 mos	292.6 (187.0)	396.4 (154.7)	159.9 (133.6)	7.3, $p < .001$, $d = 1.6$
30 mos	505 6 (157.9)	569.3 (108.6)	419.3 (174.5)	4.7, $p < .001$, $d = 1.0$

[a] Groups based on percentile for words produced on the CDI: Words & Sentences at 18 months (see text).

[b] Hollingshead 4-factor Index of Social Status (Hollingshead, 1975)

[c] Number of words reported as “understands & says” on the CDI: Words & Sentences

Table 2

Mean (SD) for accuracy (Acc) and reaction time (RT) in TD and LT children at 18 months

		Language Group[a]		
	Full Sample (*n*=82)	**TD (*n*=46)**	**LT (*n*=36)**	***t*(80)**
Acc: All trials[b]	.63 (.09)	.66 (.08)	.61 (.10)	2.1, $p < .04$, $d = 0.6$
Acc: Target understood[b]	.64 (.09)	.66 (.08)	.62 (.10)	1.8, $p < .08$, $d = 0.4$
RT: All trials[c]	822.6 (179.1)	789.1 (157.8)	865.4 (197.0)	2.0, $p < .05$, $d = 0.4$
RT: Target understood[c]	811.8 (174.9)	785.9 (155.3)	844.9 (194.4)	1.5, $p < .13$, $d = 0.3$

[a] TD and LT groups based on percentile for words produced on the CDI: Words & Sentences at 18 months (see text).

[b] Mean proportion looking to the target picture out of looking to the target and distracter picture from 300 to 1800 msec from noun onset on distracter- and target-initial trials, computed over all trials and target word understood trials (see text).

[c] Mean latency to initiate an eye-movement (in msec) from the distracter to the target picture on distracter-initial trials, compute over all trials and target word understood trials (see text).

Table 3

Summary of Level 1 (Unconditional) models

	Level 1: Unconditional		
	Model 1: Intercept only	**Model 2: Linear**	**Model 3: Quadratic**
Model Fit (-2LL)	4397.9	3958.5	3823.6
# of Parameters	3	6	10
Fixed Effects	*Parameter estimates (se)*		
Intercept	**263.1 (14.4)****	**502.9 (19.7)****	**503.7 (17.5)****
Linear	--	**35.5 (1.3)****	**35.2 (4.1)****
Quadratic	--	--	-.04 (.35)
Random Effects	*Covariance Estimates (se)*		
Within-person	**40519.5 (3686.5)****	**5853.6 (652.1)****	**1937.7 (307.1)****
Intercept	**6645.1 (2809.8)***	**26709.3 (4991.1)****	**22872.7 (3912.3)****
Linear	--	**61.0 (22.9)****	**1085.9 (219.1)****
Quadratic	--	--	**7.7 (1.5)****

Note: *se* = standard error; *t*-statistic:

* $p < .01$; Wald *Z*:

** $p < .001$; Significant effects also indicated in bold.

Table 4

Summary of Level 2 (Conditional) growth models: Language Group, RT, Accuracy

	Level 2: Conditional		
	Model 4: Group	**Model 5: Group x RT**	**Model 6: Group x Accuracy**
Model Fit (-2LL)	3763.3	3744.0	3729.0
# of Parameters	13	19	19
Fixed Effects	*Parameter estimates (se)*		
Intercept	**420.5 (23.6)****	**717.3 (99.0)****	−46.0 (132.9)
Linear	**55.3 (5.5)****	**91.3 (23.8)****	14.7 (31.7)
Quadratic	**1.8 (0.4)****	2.7 (1.9)	1.6 (2.6)
Group x Intercept	**148.4 (31.3)****	−36.8 (141.2)	**389.6 (202.5)**$^{\#}$
Group x Linear	**−35.8 (7.3)****	**−110.5 (33.9)****	**111.1 (48.3)***
Group x Quadratic	**−3.3 (0.6)****	**−7.4 (2.8)****	5.4 (4.0)
RT x Intercept	--	**−0.4 (0.1)****	--
RT x Linear	--	−0.04 (0.03)	--
RT x Quad	--	−0.01 (0.01)	--
RT x Group x Intercept	--	0.2 (0.2)	--
RT x Group x Linear	--	**0.09 (0.04)***	--
RT x Group x Quad	--	0.01 (0.01)	--
Accuracy x Intercept	--	--	**747.8 (210.2)****
Accuracy x Linear	--	--	65.0 (50.1)
Accuracy x Quad	--	--	0.2 (4.1)
Accuracy x Group x Intercept	--	--	−406.3 (311.6)
Accuracy x Group x Linear	--	--	**−226.3 (74.4)****
Accuracy x Group x Quad	--	--	**−13.2 (6.1)***
Random Effects	*Covariance Estimates (se)*		
Within-person	**1937.6 (307.1)****	**1933.3 (306.1)****	**1943.2 (307.8)****
Intercept	**17456.3 (3064.8)**	**15224.3 (2713.2)****	**14405.4 (2591.2)****
Linear	**769.2 (219.1)****	**707.1 (161.1)****	**647.4 (152.5)****
Quadratic	**5.0 (1.1)***	**4.8 (1.1)****	**4.3 (1.0)****

Note: *se* = standard error; *t*-statistic,

$^{\#}$$p < .07$,

*$p < .05$, $p < .01$;

**Wald Z: $p < .001$; Significant effects also indicated in bold.