Speed of Language Comprehension at 18 Months Old Predicts School-Relevant Outcomes at 54 Months Old in Children Born Preterm

Virginia A. Marchman, PhD,* Elizabeth C. Loi, BA,† Katherine A. Adams, BA,‡ Melanie Ashland, BA,* Anne Fernald, PhD,* Heidi M. Feldman, MD, PhD†

ABSTRACT: Objective: Identifying which preterm (PT) children are at increased risk of language and learning differences increases opportunities for participation in interventions that improve outcomes. Speed in spoken language comprehension at early stages of language development requires information processing skills that may form the foundation for later language and school-relevant skills. In children born full-term, speed of comprehending words in an eye-tracking task at 2 years old predicted language and nonverbal cognition at 8 years old. Here, we explore the extent to which speed of language comprehension at 1.5 years old predicts both verbal and nonverbal outcomes at 4.5 years old in children born PT. Method: Participants were children born PT (n = 47; ≤32 weeks gestation). Children were tested in the “looking-while-listening” task at 18 months old, adjusted for prematurity, to generate a measure of speed of language comprehension. Parent report and direct assessments of language were also administered. Children were later retested on a test battery of school-relevant skills at 4.5 years old. Results: Speed of language comprehension at 18 months old predicted significant unique variance (12%–31%) in receptive vocabulary, global language abilities, and nonverbal intelligence quotient (IQ) at 4.5 years, controlling for socioeconomic status, gestational age, and medical complications of PT birth. Speed of language comprehension remained uniquely predictive (5%–12%) when also controlling for children’s language skills at 18 months old. Conclusion: Individual differences in speed of spoken language comprehension may serve as a marker for neuropsychological processes that are critical for the development of school-relevant linguistic skills and nonverbal IQ in children born PT.

(Please insert relevant terms: prematurity, speed of processing, language, nonverbal IQ.)

Premature birth affects approximately 10% of all births and is associated with increased risk of adverse neurodevelopmental outcomes, especially for those born very or extremely preterm (PT). Language deficits are among the adverse outcomes affecting children born PT. Early identification of language deficits is important because those with poor early language skills are at increased risk of later adverse outcomes, including poor literacy and academic skills. Language delays among children born PT are frequently identified during the toddler years and persist to adolescence. However, language outcomes after PT birth show variability at every developmental level. In this study, we evaluated the use of an experimental task that measures speed of language comprehension to identify which toddlers born PT would be at the highest risk of adverse outcomes and to interrogate the nature of their difficulties.

Rather than a unified construct, language ability can be conceptualized as an ensemble of critical subskills, including speed of processing, attention, and verbal memory. The standardized tests and parent report measures traditionally used in clinical practice assess accumulated knowledge, such as vocabulary size or grammatical skills, but do not specifically evaluate the component subskills. Directly assessing language subskills may be useful for understanding continuities of early skills and later outcomes within and beyond the language domain and may explain the neuropsychological processes underlying language delays.

Measuring underlying subskills in young children who have limited tolerance for behavioral testing can be challenging. However, a low-demand eye-tracking procedure can assess the speed of real-time spoken language comprehension. The “looking-while-listening” (LWL) task monitors children’s eye movements while they look at 2 pictures in response to verbal stimuli directing their attention to the target (e.g., “Where’s the doggy?”) and away from the distracter picture. Speed of language

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comprehension is reflected in reaction time (RT) to shift the gaze from the distracter to the target. Previous studies have found that full-term (FT) children who showed faster RTs at 18 months old had more rapid vocabulary growth over the second and third years and higher intelligence quotient and working memory scores at 8 years old. Thus, how quickly FT children comprehend familiar words in this eye-tracking paradigm reflects information processing skills that support early vocabulary development and long-term verbal and nonverbal learning. The LWL task offers a promising approach for isolating neuropsychological processes that are fundamental to learning across many domains and has the potential for identifying weaknesses that may accumulate to cause later disability in clinical populations, such as children born PT.

Studies with school-aged children and adolescents born PT implicate slow language processing speed as a contribution to language and reading deficits. These results suggest that speed of language processing may prove to be a reliable measure of individual differences at early ages and a predictor of neurodevelopmental progress. Among children born PT, speed of language comprehension on the LWL task was associated with standardized measures of general language at 18 months old corrected age and predicted receptive vocabulary scores at age 3 years old.

Current Study

In this study, we extend the previous findings by assessing the contributions of speed of language comprehension in the looking-while-listening task in preterm children at age 18 months old, adjusted for prematurity, to language abilities and also to nonverbal intelligence at 4.5 years old. We hypothesized that speed of language processing would predict not only vocabulary and general language skills but also nonverbal intelligence quotient at 4.5 years old, controlling for demographic and medical variables known to be associated with outcomes in this population.

METHOD

Participants

Participants were 47 children (22 females) with gestational age (GA) ≤32 weeks and birth weight (BW) <1800 g from an ongoing longitudinal study. Data on the predictor variables have been reported on previously for a subset of these children. Families were recruited from the neonatal intensive care unit, the High-Risk Infant Follow-up Clinic, or a research registry. Exclusionary criteria were conditions, such as visual/auditory impairments, that would limit participants from engaging in the study’s tasks. All children were primarily English learners, exposed to <25% of another language. The research protocol was approved by a university’s institutional review board; parents gave signed consent at each visit.

Children were tested at 18 months old, adjusted for prematurity (mean = 18.7; range = 18.0–20.3 months; chronological age: mean = 21.1, range = 20.2–22.8 months). Follow-up language and nonverbal intelligence quotient (IQ) measures were administered when the children were 4.5 years of chronological age (mean = 4.5, range = 4.3–4.9 years). An additional 25 participants were tested at 18 months old but did not return for testing at 4.5 years old because of the conclusion of funding.

Table 1 shows the characteristics of the sample. We measured socioeconomic status (SES) because it has been associated with neurodevelopmental outcomes in preterm (PT) and full-term children. Participants were primarily from mid-to-high SES, as classified using a modification of the Hollingshead Four-Factor Index, a composite based on parents’ education and occupation (range = 8–66). Poor outcomes after PT birth have been linked to GA and BW. In this sample, GA and BW were highly correlated, and we used GA in analyses.

Outcomes have also been associated with medical and neurological complications of PT birth. Trained research assistants in consultation with the last author coded the presence/absence of 12 medical and neurological conditions associated with prematurity (Table 1). A composite score summed all medical conditions to generate a proxy for the severity of medical complications in the perinatal period.

Predictor Variables, Measures at Age 18 Months Old of Adjusted Age

Vocabulary Size

Early vocabulary skills were assessed using the MacArthur-Bates Communicative Development Inventory: Words & Gestures (MB-CDI: W&G), a reliable, valid parent report instrument. Parents marked words that their child “understands” and “understands and says.” Total comprehension and production vocabulary sizes were derived (396 max). Percentiles were derived based on age and adjusted for degree of prematurity.

Cognition and Receptive/Expressive Language

Trained examiners administered the Bayley Scales of Infant and Toddler Development, third edition. Scores were computed for cognitive, receptive language, and expressive language subscales, as well as the total language composite. The language composite was used as a comprehensive evaluation of receptive and expressive language skills. Scaled scores were converted to standard full-scale scores based on adjusted age.

Speed of Language Comprehension

We used the looking-while-listening (LWL) procedure to measure speed of language comprehension. Children were tested in 2 visits approximately 1 week apart, and the data were later combined across sessions. The child sat on the caregiver’s lap while pairs of pictures of objects appeared on a screen and a prerecorded voice named 1 of the pictures. A video camera between the pictures provided a video record of the child’s looking responses. Each session lasted approximately 5 minutes. Caregivers’ vision was blocked so that they could not inadvertently bias their child’s responses.
Visual stimuli were color pictures presented in fixed pairs matched for animacy and salience. Target order and picture position were counterbalanced. Pictures were displayed for 2 seconds before speech onset and for 1 second after sound offset. Auditory stimuli presented the target noun in sentence-final position followed by an attention getter (e.g., "Where's the doggy? Do you like it?"). Target nouns were selected to be familiar to children of this age range: ball–shoe, birdie–kitty, baby–doggy, and book–car. Target nouns were presented 4 times as target and distracter, with 4 filler trials, yielding 64 test trials. Because the LWL captures individual differences in the speed with which children process words that are familiar to them,15 trials with target words which the parent reported that the child did not understand were excluded from analysis on a child-by-child basis. All children were reported to know at least 5 target words (mean 5 7.5, 93%).

All LWL sessions were coded offline based on the video recordings of the child’s eye movements by trained research assistants who were unaware of target side. Trials where the participant was inattentive or the parent interfered were excluded. For each 33-millisecond interval of each trial, eye gaze was coded as either fixed on 1 of the images (left or right), moving between the images, or not looking at either image. Trials were later designated as target-initial or distracter-initial based on where the child was fixated at target noun onset.

Reaction time (RT) was computed for each participant collapsing across all trials from each of the testing sessions. RT is the mean latency in milliseconds to initiate a gaze shift from distracter to target on all distracter-initial trials during a window of 300 to 1800 milliseconds after target noun onset. Shifts initiated outside the window were excluded from computation of RT because they were less likely to be in response to the verbal stimulus. All children contributed at least 2 valid shifts to the computation of RT (mean = 16.7 trials; range = 2–30). To establish reliability, 25% of the sessions were randomly selected and recoded. Intercoder agreement was 96% for the proportion of frames within the window that were identified as on the target versus the distracter. The proportion of trials on which RT agreed within 1 frame was 100%.

### Outcome Variables, Measured at Age 4.5 Years Old

#### Receptive Vocabulary

Children’s receptive vocabulary was assessed using the Peabody Picture Vocabulary Test, fourth edition (PPVT-4).28 Standard scores were based on chronological age. One child was missing a PPVT-4 score, so analyses with this outcome are based on n = 46.

#### General Language

Children’s language skills were assessed using the Clinical Evaluation of Language Fundamentals-Preschool-2 (CELF-P2).29 Standard scores were derived for core language based on chronological age. One child was...
missing a score on the CELF-P2, yielding a sample size for this outcome measure of n = 46. For selected analyses, children were classified into higher- (n = 22) and lower-language (n = 24) groups based on a median split of standard scores (median = 106).

**Nonverbal Intelligence Quotient**

Nonverbal IQ was assessed with the Brief-IQ subscale of the Leiter International Performance Scale-Revised.30 Administration and responses are nonverbal, capturing skill in problem solving and reasoning independent of a child’s language abilities. Standard scores were based on chronological age. Two children were missing scores on this outcome, so final analyses are based on n = 45. Children were classified based on a median split (median = 100) into higher- (n = 24) and lower-IQ (n = 21) groups.

**Data Analysis**

We derived descriptive statistics for the predictor and outcome variables. We applied a series of hierarchical multiple regressions to explore the predictive contribution of RT at 18 months old to outcomes at 4.5 years old. SES, GA, and medical risk composite scores were the control variables. We explored the predictive contribution of RT on each outcome measure beyond the control variables. We also explored the contribution of parent-reported vocabulary size and scores on a standardized test of language on outcomes beyond the control variables. Finally, we assessed the unique contribution of RT beyond demographic, medical, and scores on the early knowledge-based language and cognitive assessments. All tests were two-tailed, and levels of statistical significance were set at p < 0.05.

**RESULTS**

**Description of Sample Performance**

At 18 months old, participants were reported to comprehend approximately 200 words and to produce approximately 65 words, on average (Table 2). These scores placed children significantly below normative levels on both measures; comprehension: \( t(46) = 4.7, p = 0.001, d = 0.62; \) production: \( t(46) = 3.9, p = 0.001, d = 0.57. \) Comprehension and production vocabulary size measures were correlated, \( r(46) = 0.67, p = 0.001. \) Mean scaled scores for the total language composite on the Bayley Scales of Infant and Toddler Development, third edition (BSID-III) (Table 2) were not significantly different below normative expectations for corrected age, \( t(46) = 1.2, p = 0.24, d = 0.17. \) Scores on the BSID-III were significantly correlated (rs = 0.52–0.63), and we chose the total language composite as the primary measure in our predictive models. In the looking-while-listening task, the mean reaction time (RT) was approximately 790 milliseconds. RT was moderately correlated with scores from the MB-CDI and BSID-III (rs = –0.27 to –0.50).

At 4.5 years old, children were, on average, performing above expected normative levels on the Peabody Picture Vocabulary Test, fourth edition (PPVT-4), \( t(45) = 3.5, p = 0.001, d = 0.46 \) and the Clinical Evaluation of Language Fundamentals-Preschool 2 (CELF-P2) \( t(45) = 2.1, p = 0.04, d = 0.31. \) Scores on the Leiter International Performance Scale-Revised (Leiter-R) were not significantly different from expected levels, \( t(44) = 1.1, p = 0.27, d = 0.17. \) For all measures, some children scored >1 SD below the normative mean (PPVT-4: \( n = 5, 11%; \) CELF-P2: \( n = 4, 9%; \) Leiter-R: \( n = 11, 24%. \) The 2 language measures were strongly correlated, \( r(45) = 0.71, p < 0.0001; \) both were moderately correlated with nonverbal intelligence quotient (IQ): PPVT-4, \( r(43) = 0.45, p < 0.002; \) CELF-P2, \( r(45) = 0.49, p < 0.001. \)

**Predicting Performance on Outcome Measures at 4.5 Years Old**

**Receptive Vocabulary**

In Table 3, the 3 control variables, socioeconomic status, gestational age (GA), and medical risk accounted for approximately 29% of the variance in PPVT-4, \( F(3,42) = 5.7, p = 0.002; \) GA was a unique predictor (Model 1). RT contributed 15% additional variance (Model 2), \( F(1,41) = 12.6, p = 0.001. \) Without consideration of RT, production vocabulary size (MB-CDI) and total language (BSID-III) contributed more than 23% variance, 0.001, \( d = 0.46 \) and the Clinical Evaluation of Language Fundamentals-Preschool 2 (CELF-P2), \( t(45) = 2.1, p = 0.04, \) \( d = 0.31. \) Scores on the Leiter International Performance Scale-Revised (Leiter-R) were not significantly different from expected levels, \( t(44) = 1.1, p = 0.27, d = 0.17. \) For all measures, some children scored >1 SD below the normative mean (PPVT-4: \( n = 5, 11%; \) CELF-P2: \( n = 4, 9%; \) Leiter-R: \( n = 11, 24%. \) The 2 language measures were strongly correlated, \( r(45) = 0.71, p < 0.0001; \) both were moderately correlated with nonverbal intelligence quotient (IQ): PPVT-4, \( r(43) = 0.45, p < 0.002; \) CELF-P2, \( r(45) = 0.49, p < 0.001. \)

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**Table 3.** Prediction to PPVT-4 at 4.5 Years From 18 Months Demographic, Medical, Language, and Language Processing Measures (n = 46)

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI: SES^a</td>
<td>0.36 (0.29)</td>
<td>0.23 (0.26)</td>
<td>0.38 (0.25)</td>
</tr>
<tr>
<td>Gestational age (GA)</td>
<td>0.61 (0.26)^*</td>
<td>0.76 (0.24)^**</td>
<td>0.38 (0.23)</td>
</tr>
<tr>
<td>Medical risk^b</td>
<td>−0.79 (1.73)</td>
<td>1.53 (1.70)</td>
<td>−0.71 (1.49)</td>
</tr>
<tr>
<td>MB-CDI: vocabulary production^c</td>
<td>—</td>
<td>—</td>
<td>0.11 (0.04)^**</td>
</tr>
<tr>
<td>BSID-III: language^d</td>
<td>—</td>
<td>—</td>
<td>0.15 (0.16)</td>
</tr>
<tr>
<td>LWL: RT^e</td>
<td>—</td>
<td>−0.05 (0.02)^**</td>
<td>—</td>
</tr>
<tr>
<td>r^2-change</td>
<td>—</td>
<td>15.2%^**</td>
<td>23.2%^**</td>
</tr>
<tr>
<td>Total r^2</td>
<td>29.1%^**</td>
<td>44.3%^**</td>
<td>52.4%^**</td>
</tr>
</tbody>
</table>

Data are presented as unstandardized B (standard error). *p < 0.05, **p < 0.01, significant effects also in bold. ^aHollingshead Four-Factor Index of Socioeconomic Status (HI: SES). ^bComposite score based on presence/absence of 12 conditions (Table 1). ^cReported words produced on the MB-CDI: Words & Gestures at 18 months old. ^dStandard scores on the language composite (expressive and receptive subscales) of the BSID-III. ^eMean latency to shift to target picture on distractor-initial trials in the looking-while-listening task, including only shifts that occurred between 300 and 1800 milliseconds from target noun onset. BSID-III, Bayley Scales of Infant and Toddler Development, third edition; MB-CDI, MacArthur-Bates Communicative Development Inventory; LWL, looking-while-listening; PPVT-4, Peabody Picture Vocabulary Test, fourth edition; RT, reaction time.

F(2,40) = 9.8, p = 0.001, beyond control variables, but only production vocabulary size contributed significant unique variance (Model 3). In the final model, RT added nearly 5% variance beyond all other predictors, F(1,39) = 4.4, p = 0.06 (Model 4); GA, production vocabulary size, and RT contributed unique variance to the outcome. All the predictors accounted for nearly 60% of the variance, F(6,39) = 8.6, p = 0.001. A similar pattern of results was found when vocabulary comprehension was entered in the models; RT contributed 6.5% unique variance, F(1,39) = 5.3, p = 0.03, beyond all other predictors.

**General Language**

In Table 4, of the control variables, only medical risk accounted for significant unique variance in CELF-P2 scores (Model 5), but the overall model accounted for approximately 21% of the variance. Adding RT accounted for approximately 30% additional variance, F(1,41) = 26.3, p < 0.0001 (Model 6). Without consideration of RT, production vocabulary size (MB-CDI) and total language (BSID-III) also contributed approximately 30% additional variance after control variables, F(2,40) = 12.1, p = 0.001; production vocabulary size, medical risk, and BSID-III all remained unique predictors (Model 7). In the final model (Model 8), RT contributed nearly 12% additional variance beyond all other predictors, F(1,39) = 12.3, p = 0.001. None of the other predictors contributed unique variance. Taken together, the predictors accounted for more than 60% of the variance in CELF-P2 scores. A similar pattern of results was found when controlling for comprehension vocabulary size, with RT contributing 14.3% unique variance beyond all other predictors, F(1,39) = 19.4, p = 0.001.

The relation between RT at 18 months and later general language skill is illustrated by the time course plot of children’s looking from the distractor to the target (Fig. 1) as a function of time in milliseconds from target noun onset; noun offset is indicated by the vertical dashed line. As the stimulus sentence unfolds in time, all children increased their proportion of looking to the correct picture. However, children with higher CELF-P2 scores increased their proportion of looking earlier in the stimulus sentence and reached a higher overall level of correct looking compared with children with lower CELF-P2 scores. This difference in looking patterns is also reflected in faster mean RTs to shifting from the distractor to target, on average, in children with higher

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**Table 4.** Prediction to Core Language (CELF-P2) at 4.5 Years From 18 Months Demographic, Medical, Language, and Language Processing Measures (n = 46)

<table>
<thead>
<tr>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI: SES^a</td>
<td>0.32 (0.23)</td>
<td>0.14 (0.19)</td>
<td>0.29 (0.19)</td>
</tr>
<tr>
<td>Gestational age (GA)</td>
<td>−0.01 (0.21)</td>
<td>0.17 (0.17)</td>
<td>−0.18 (0.18)</td>
</tr>
<tr>
<td>Medical risk^b</td>
<td>−2.91 (1.38)^*</td>
<td>−0.78 (1.2)</td>
<td>−2.74 (1.14)^*</td>
</tr>
<tr>
<td>MB-CDI: vocabulary production^c</td>
<td>—</td>
<td>—</td>
<td>0.06 (0.03)^*</td>
</tr>
<tr>
<td>BSID-III: language^d</td>
<td>—</td>
<td>—</td>
<td>0.29 (0.13)^*</td>
</tr>
<tr>
<td>LWL task: RT^e</td>
<td>—</td>
<td>−0.05 (0.01)^**</td>
<td>—</td>
</tr>
<tr>
<td>r^2-change</td>
<td>—</td>
<td>29.5%^**</td>
<td>28.8%^**</td>
</tr>
<tr>
<td>Total r^2</td>
<td>21.6%^*</td>
<td>51.0%^**</td>
<td>50.4%^**</td>
</tr>
</tbody>
</table>

Data are presented as unstandardized B (standard error). *p < 0.05, **p < 0.01, significant effects also in bold. ^aHollingshead Four-Factor Index of Socioeconomic Status (HI: SES). ^bComposite score based on presence/absence of 12 medical conditions (Table 1). ^cReported words produced on the MB-CDI: Words & Gestures at 18 months old. ^dStandard scores on the language composite (expressive and receptive) of the BSID-III. ^eMean latency to shift to target picture on distractor-initial trials in the looking-while-listening task, including only shifts that occurred between 300 and 1800 milliseconds from target noun onset. BSID-III, Bayley Scales of Infant and Toddler Development, third edition; MB-CDI, MacArthur-Bates Communicative Development Inventory; CELF-P2, Clinical Evaluation of Language Fundamentals-Preschool-2; LWL, looking-while-listening; RT, reaction time.
Medical risk factors. The dashed vertical line indicates target noun offset.

Gestational age 2

BSID-III: language scores on the language composite (expressive and receptive) of the BSID-III.27 Mean latency to shift to target picture on distracter-initial trials in the looking-while-listening (LWL) task,15 including only shifts that occurred between 300 and 1800 milliseconds from target noun onset. BSID-III, Bayley Scales of Infant and Toddler Development, third edition; language scores, t
t

Language Processing Speed in Children Born Preterm

Data are presented as unstandardized B (standard error). *p < 0.05, **p < 0.01, significant effects also in bold. aHollingshead Four-Factor Index of Socioeconomic Status (HI: SES).23

Nonverbal Intelligence Quotient

In Table 5, demographic and medical factors accounted for 20% of the variance in Leiter-R; however, none of the covariates made a significant unique contribution (Model 9). RT accounted for an additional 12% of the variance, \( F(2,39) = 2.0, p = 0.01 \) (Model 10). Without RT in the model, none of the other variables contributed beyond the control variables (Model 11). RT at 18 months old contributed approximately 10% variance beyond the control variables, \( F(1,36) = 10.0, p = 0.003 \) (Model 12), and was the only significant unique predictor in the final model. Together, all predictors accounted for approximately 36% of the variance in nonverbal IQ. A similar pattern was observed when controlling for vocabulary comprehension; RT contributed 10.8% unique variance, \( F(1,38) = 6.1, p = 0.02 \). The pattern remained the same when controlling for scores on the cognitive subtest of the BSID-III, \( t(1,38) = 4.6, p = 0.04 \), with RT contributing 8.0% unique variance.

The plot of the time course of children’s looking (Fig. 2) shows that children with higher nonverbal IQ at age 4.5 years old displayed different patterns of looking compared with children with lower nonverbal IQ. Children with higher IQ increased their looking to the target sooner in the sentence and reached an overall higher proportion of correct looking compared with children with lower IQ scores. These looking patterns are also reflected in faster mean RTs to shifting from distracter to target for children with higher (mean = 712 milliseconds, SD = 130) compared with lower nonverbal IQs (mean = 868, SD = 174). \( t(43) = 3.4, p = 0.001, d = 1.01 \).

DISCUSSION

Speed of language comprehension at age 1.5 years old predicted individual differences in receptive vocabulary, general language skills, and nonverbal intelligence at age 4.5 years old in children born preterm (PT). Importantly, reaction time (RT) in the looking-while-listening (LWL) task at age 18 months old, adjusted for the degree of prematurity, accounted for unique variance in neurodevelopmental outcomes that were not captured by demographic variables, the number of medical complications, and traditional assessments of language knowledge. These results extend earlier findings showing that RT at 18 months old strongly predicted receptive vocabulary at 3 years old in children born PT.36 Here, RT also predicted individual differences in general receptive and expressive language skills at age 4.5 years old. Early speed of language comprehension also uniquely predicted children’s nonverbal intelligence quotients (IQs), whereas the results of traditional language assessments did not. This finding suggests that early RT indexes information processing skills that support learning in both the verbal and nonverbal domains as has been found in children born full-term (FT).17

Speed of language comprehension in the LWL task reflects multiple information processing skills, including

(mean = 716 milliseconds, SD = 138) compared with lower (mean = 841 milliseconds, SD = 158) language scores, \( t(44) = 2.8, p = 0.007, d = 0.84 \).

**Table 5.** Prediction to Non-verbal IQ (Leiter-R) at 4.5 Years From 18 Months Demographic, Medical, Language, and Language Processing Measures (n = 45)

<table>
<thead>
<tr>
<th></th>
<th>Model 9</th>
<th>Model 10</th>
<th>Model 11</th>
<th>Model 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI: SESa</td>
<td>0.62 (0.33)</td>
<td>0.47 (0.32)</td>
<td>0.64 (0.33)</td>
<td>0.54 (0.32)</td>
</tr>
<tr>
<td>Gestational age</td>
<td>-0.05 (0.30)</td>
<td>0.08 (0.29)</td>
<td>-0.21 (0.31)</td>
<td>0.01 (0.31)</td>
</tr>
<tr>
<td>Medical riskb</td>
<td>-3.40 (1.98)</td>
<td>-1.44 (1.99)</td>
<td>-3.71 (1.97)</td>
<td>-1.86 (2.02)</td>
</tr>
<tr>
<td>MB-CDI: vocabulary productionc</td>
<td>---</td>
<td>---</td>
<td>0.08 (0.05)</td>
<td>0.07 (0.05)</td>
</tr>
<tr>
<td>BSID-III: languaged</td>
<td>---</td>
<td>---</td>
<td>-0.03 (0.23)</td>
<td>-0.24 (0.23)</td>
</tr>
<tr>
<td>LWL task: RT e</td>
<td>-0.05 (0.02)</td>
<td>---</td>
<td>-0.05 (0.02)</td>
<td>---</td>
</tr>
<tr>
<td>( r^2 )-change</td>
<td>12.1%*</td>
<td>6.6%</td>
<td>9.4%*</td>
<td>35.7%**</td>
</tr>
<tr>
<td>Total ( r^2 )</td>
<td>19.8%*</td>
<td>31.9%**</td>
<td>26.4%*</td>
<td>35.7%**</td>
</tr>
</tbody>
</table>

Data are presented as unstandardized B (standard error). *p < 0.05, **p < 0.01, significant effects also in bold. aHollingshead Four-Factor Index of Socioeconomic Status (HI: SES).23 bComposite score based on presence/absence of 12 medical conditions (Table 1). cReported words produced on the MB-CDI: Words & Gestures26 at 18 months old. dStandard scores, on the language composite (expressive and receptive) of the BSID-III.27 eMean latency to shift to target picture on distracter-initial trials in the looking-while-listening (LWL) task,15 including only shifts that occurred between 300 and 1800 milliseconds from target noun onset. BSID-III, Bayley Scales of Infant and Toddler Development, third edition; MB-CDI, MacArthur-Bates Communicative Development Inventory; IQ, intelligence quotient; Leiter-R, Leiter International Performance Scale- Revised, RT, reaction time.
efficiency in encoding visual and auditory information, retaining that information in memory, and appropriately directing eye movements to the correct referent. The measure may also index language knowledge; words that are well known may be processed more quickly than words that are less familiar. Speed of language comprehension thus reflects a host of neuropsychological processes that guide early linguistic skill and that are continuous with later assessments of language, problem-solving, reasoning, attention, and working memory. Traditional measures of early language knowledge, such as parent reports of vocabulary size and standardized assessments of receptive and expressive skills, capture children’s accumulated knowledge; by contrast, RT reflects neuropsychological processes that facilitate efficient uptake of both linguistic and nonlinguistic information during real-time interactions. Accumulated language knowledge and language processing skills are both important and intercorrelated. The current findings show that children’s general speed of information uptake during real-time language comprehension accounted for variance in school-relevant verbal and nonverbal skills.

Parent reports of vocabulary size also uniquely predicted later language outcomes, controlling for demographic and medical variables. However, associations of vocabulary size to later nonverbal IQ were not significant. Thus, early vocabulary size was a good estimate of accumulated linguistic knowledge that related to later language measures but showed limited continuity with nonverbal measures that require a broader range of neuropsychological processes. Interestingly, scores on the Bayley Scales of Infant and Toddler Development, third edition (BSID-III), a direct assessment of language knowledge that is widely used with clinical populations, showed independent contributions only to later Clinical Evaluation of Language Fundamentals-Preschool-2 scores in this sample. Future studies should continue to explore the long-term independent continuities of measures such as the BSID-III in this population to language and cognitive outcome measures.

Where do individual differences in language processing speed come from? One possibility is the down-stream effects of early neurological disturbances associated with PT birth. Alterations in cerebral volumes and white matter pathways connecting them may influence speed of processing. While medical risk and RT were modestly correlated here, $r(47) = 0.37, p < 0.01$, the unique contributions of RT to outcomes demonstrated here were above and beyond variance in an index of perinatal medical complications and injuries. This suggests that RT may reflect underlying variation in neurological processes that are not captured by a simple measure of medical risk.

Another possibility, consistent with a growing literature, is that the quantity and quality of the talk that children hear from caregivers affects the development of vocabulary and language processing skills. In a recent study examining caregiver talk in a matched group of FT and PT children, more caregiver talk was associated with better language outcomes in both FT and PT children and among PT children who were more or less vulnerable to the adverse consequences of PT birth. Interventions that support increased caregiver-child engagement may effectively shape children’s learning outcomes by tuning up those language processing skills that support learning in both PT and FT children.

**Limitations**

The sample size was relatively small and had a high proportion of children from affluent, highly educated backgrounds. Given the association between PT birth and socioeconomic status, our results may not generalize to a more diverse sample of PT children. Our study assessed nonverbal outcomes using a single assessment measure. It is not known whether children’s speed of language comprehension would be associated with other nonverbal skills, such as attention and executive functioning, that are also critical for school success.

Our index of medical risk was the sum of an equal weighting of many different conditions that have been associated with PT birth. Further research is needed to determine which of these risk factors or combination of risk factors are most associated with adverse consequences in this population. Finally, we assessed outcomes only at 4.5 years. Future studies should explore the longer-term impact of early speed of language comprehension in this population.

**Implications and Conclusions**

Early indices of language progress by parent report and direct standardized assessments accounted for variation in later language outcomes in children born PT. However, individual differences in the speed of language comprehension at 18 months old accounted for significant unique variation in both verbal and nonverbal outcomes at 4.5
years. Thus, measures of early efficiency in processing linguistic input in real time capture important information about early neuropsychological processes that traditional measures do not. Speed of language comprehension at young ages may serve as the foundation for the development of a broad range of verbal and nonverbal neuropsychological processes that are relevant to academic and life success in children across a range of skill levels. Understanding the causes and consequences of the development of early speed of real-time language comprehension may elucidate and shape treatments of developmental delays in children born PT.

REFERENCES