Associations between early efficiency in language processing and language and cognitive outcomes in children born full term and preterm: Similarities and differences

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Abstract

Associations between children's early language processing efficiency and later verbal and non-verbal outcomes shed light on the extent to which early information processing skills support later learning across different domains of function. Examining whether the strengths of associations are similar in typically developing and at-risk populations provides an additional lens into the varying routes to learning that children may take across development. In this follow-up study, children born full-term (FT) and preterm (PT) (n=94, 49 FT, 45 PT) were assessed in the Looking While Listening (LWL) task at 18 months (corrected for degree of prematurity in PT group). This eye-tracking task assesses efficiency of real-time spoken language comprehension in terms of accuracy and speed (RT) of processing. At 4 ½ years, children were assessed on standardized tests of receptive vocabulary, expressive language, and non-verbal IQ. Language processing efficiency was associated with the two language outcomes (r^2-change ranged from 7.0 to 19.7%, $p < 0.01$), controlling for age at test and SES. Birth group did not moderate the effects on language skills, suggesting similar mechanisms of learning in these domains for PT and FT children. However, birth group moderated the association between speed and non-verbal IQ (r^2 change 4.5, $p < 0.05$), such that an association was found in the PT but not the FT group. This finding suggests that information processing skills reflected in efficiency of real-time language processing may be recruited to support learning in a broader range of domains in the PT compared to the FT group.

Studies of early language development seek to explicate the mechanisms underlying how children learn via exposure to speech. Over the last few decades, research has demonstrated that young children, like adults, process speech incrementally as it unfolds in time[1,2] and efficiently extract aspects of the speech signal that can support language learning[3–5]. One frequently used experimental paradigm for assessing children's language processing efficiency is "looking-while-listening" (LWL), a low-demand, eye-tracking task that assesses real-time spoken language comprehension[6]. In this task, children's eye movements are monitored as they look at two pictures while a voice directs their attention to a target picture (e.g., "Where's the doggy?"). Efficiency of language comprehension is reflected in two measures. Looking time, or *accuracy*, is defined as the proportion of time looking at the target and not at the distracter. Processing speed, or *reaction time* (RT), is defined as the number of milliseconds (ms) to shift gaze from the distracter to the target picture in response to the verbal cue. These measures capture the child's ability to engage with the speech signal, interpret it accurately, and map that speech onto the visual scene in real time.

The efficiency with which children can process language in real-time has been revealing as a measure of individual differences that has substantial predictive validity. For example, children who show more efficient language comprehension at 18 months show larger vocabulary size and more rapid vocabulary growth over the second and third years of life than children with less efficient processing[4,5,7,8]. One interpretation of these links is that early language processing efficiency captures variation in foundational skills that underlie early language learning including attention, working memory, and processing speed[8]. More specifically, faster speed of processing may indicate or allow for more efficient allocation of finite processing resources than slower speed, so that incoming information in the speech signal is processed more effectively, leading to faster vocabulary learning. Another possibility is that more efficient processing reflects more effective chunking of information in the incoming speech signal, such that less information is required to encode word form-meaning mappings, thereby, facilitating vocabulary growth[1,7]. At the foundation of these theories is that language learning can be conceptualized as a type of skill acquisition, requiring component processes that can be tuned up with experience in real-time language comprehension[9,10]. The evidence that variation in early language experience, as reflected in measures of the amount of language the child is exposed to at home, may contribute to the development of language processing efficiency further supports this view[11,12].

It is important to take a developmental approach, exploring patterns of relations longitudinally, at different periods of development, and in relation to different domains of function[13]. To this end, it is revealing that variation in early language processing efficiency is associated with children's skills beyond vocabulary development. For example, individual differences in early language processing efficiency in toddlerhood has been linked to variation in morphosyntactic skill in preschool-aged children[1,7,14]. Early processing efficiency has also been shown to be associated with later verbal intelligence quotient and verbal working memory scores in school-aged children[15]. Associations between early processing efficiency and a range of cognitive outcomes suggests continuity between skills involved in early real-time language processing and those that are involved in mastering a range of later complex thinking, learning, and problem-solving skills. As such, measures of early language processing efficiency capture not only what children know, but also how efficiently children can process information in real time[8], a skill that forms the foundation for learning in a variety of domains.

Conceptualizing language as skill acquisition in children leaves open the possibility that component skills may be recruited differently, or to different extents, in different populations[16,17]. An important line of inquiry is the degree to which the LWL task is useful for predicting later outcomes in clinical populations. The critical issue is whether performance in the LWL task is reliable and valid in children at increased risk for language delays compared to children who are typically developing[18,19]. Premature birth, which affects approximately 10.2% of all births in the US[20], is associated with increased risk of adverse neurodevelopmental outcomes, especially for those infants born very preterm (PT: birth at < 32 weeks gestation) or extremely PT (birth at < 28 weeks gestation)[21]. It is well-established that children born PT are at increased risk for language-related deficits compared to their full-term (FT) peers[22–28]. Moreover, PT birth is associated with injury to and dysmaturity of white matter tracts in the brain and characteristics of white matter pathways is associated with clinical language outcomes in toddlerhood[29] as well as in prekindergarten[30]. It is intriguing to consider whether disruption in white matter circuits may adversely impact processing efficiency in language comprehension.

Recent studies using the LWL task suggest that age-related changes in language processing efficiency are comparable in children born FT and PT during the critical period between 18 and 24 months of age[31]. Moreover, associations between early processing efficiency in the LWL task and vocabulary growth from 18 to 30 months are similar in children born PT and FT[32]. However, less is known about whether individual variation in processing efficiency continues to be meaningfully linked to later developing skills in parallel ways in FT and PT children as they approach kindergarten entry. Previous studies have examined long-term associations between early processing efficiency as assessed in the LWL task only in children born PT and the results were consistent with associations found in prior studies with children born FT[33,34]. However, no studies, to our knowledge, have directly compared the relations between early language processing efficiency in the LWL task and outcomes at this important pre-kindergarten age in matched samples of children born FT and PT.

Several issues motivate the direct comparison. Children born PT are likely to be a heterogeneous group with multiple sources of neurodevelopmental issues. Accordingly, it is possible that associations which are seen earlier in development become weaker or are masked by other factors later in development in children born PT than in children born FT. On the other hand, given that children born PT are more likely to be delayed relative to children born FT, it is also possible that associations are stronger in PT compared to FT children. Associations are generally stronger between language processing efficiency and later language outcomes in younger children who tend to have smaller vocabularies than older children with larger vocabularies[7]. By comparing patterns of associations across populations of children with different risk profiles, research can lend insights into the extent to which there is variation in the kinds of component skills that children recruit for learning. If the strength of associations is similar in the two groups of children, this finding would be consistent with an explanation that a common set of underlying mechanisms support learning in children born FT and PT across the preschool period. To the extent that patterns of associations are different in different sub-populations, this finding would suggest that there are multiple possible routes to learning that vary across groups.

Evidence suggests that patterns of associations between early language processing and later outcomes in FT and PT populations may differ depending on the outcome of interest. For example, associations between early language processing efficiency and oral language skills may be parallel in PT and FT children, consistent with a model of the component skills that are similar in typically developing children and children at risk for language delays. However, associations between early processing and later non-verbal skills may be stronger or weaker in children born PT compared to the FT peers. Indeed, previous studies have shown that the strengths of association between oral language skills and phonological awareness were similar in school-aged children born FT and PT, but non-verbal skills and executive function abilities were linked to reading outcomes only in the school-aged children born PT[24]. These results were interpreted to suggest that children born PT may recruit a broader set of skills when learning to read than their FT counterparts. This interpretation is also consistent with earlier findings suggesting that language delays in preterm children may be more associated with global deficits, rather than delays in more specific component skills[35]. More research is warranted that explores associations between early language processing efficiency and verbal and non-verbal skills in these populations [23,36].

In this study, we follow-up on previous analyses conducted only in a group of children born PT, directly comparing those findings with those in a FT comparison group. Our main interest is to explore group differences in patterns of relations between measures of language processing efficiency (accuracy and RT) in toddlerhood and measures of language (receptive vocabulary and expressive language) and non-verbal IQ 3 years later. We asked:

- Do children born PT show delays in receptive vocabulary, expressive language, and non-verbal IQ at pre-kindergarten, relative to their FT peers?
- Does accuracy or speed of language processing at 18 months predict variation in receptive vocabulary, expressive language, and non-verbal outcomes at pre-kindergarten in both PT and FT children?
- Does birth group moderate the strength of these relations? And, if so, are the moderations consistent across the domains?

Method

Participants

Participants were 49 children (24 females) born full term (FT) and 45 children (23 females) born preterm (PT). Data from the children born PT have been reported earlier[34]. Recruitment of children born PT took place via the Neonatal Intensive Care Unit, the High-Risk Infant Follow-up Clinic, an intervention service provider, parent groups, or a research registry. Recruitment of the children born FT occurred via direct mail. Exclusionary criteria in both groups were conditions, such as seizure disorder or visual/auditory impairments, that would limit participants from actively engaging in the study's tasks. All children were primarily English learners, reported to be exposed to < 25% of another language. Parents gave signed consent at each visit. The research protocol was approved by a university institutional review board.

Table 1 shows the characteristics of the current sample. All children born FT were selected to be gestational age (GA) ≥ 37 weeks; all children born PT were selected to be GA ≤ 32 weeks and birth weight (BW) < 1800 grams. Socioeconomic status (SES) was measured due to associations with neurodevelopmental outcomes in PT and FT children[37]. Most mothers in both groups were primarily college-educated. SES was also estimated using a modified version of the Hollingshead Four Factor Index (HI)[38], a composite based on parents' education and occupation (possible range = 8–66). The group difference in HI was marginally significant, however, participants in both groups came from primarily higher-SES backgrounds. Medical status of the children born PT has been reported previously.[34]

Children were tested at two time points. At Time 1, children were approximately 18 months, adjusted for the degree of prematurity in the PT group. Follow-up language and non-verbal IQ measures were administered at Time 2 when the children were approximately 4 ½ years old chronological age. Participants in the FT group were significantly older than participants in the PT group, though the difference was approximately 1 month. Therefore, age at test is included as a covariate in all analyses. An additional 35 participants who were tested at 18 months did not return for testing at 4½ years because of the conclusion of funding.

Language processing efficiency at 18 months, adjusted for the degree of prematurity

Each child participated in the looking-while-listening (LWL) task[6] at 18 months of age. The child sat on the caregiver's lap while pairs of pictures of familiar objects appeared on a screen and a prerecorded voice named one of the pictures. The video-record of the child's looking responses was later coded frame-by-frame. Children were tested in two 5-minute sessions approximately one week apart.

Visual stimuli were color pictures of familiar objects, displayed for 2 seconds prior to speech onset and for 1 second after sound offset. Images were presented in fixed pairs, with order and picture position counterbalanced across participants. Auditory stimuli were simple well-formed sentences with target noun in sentence-final position, followed by an attention-getter (e.g., "Where's the doggy? Do you like it?"). Each noun was presented four times as target and four times as distracter, with 4 filler trials, yielding 64 test trials. Selection of the stimulus words was based on familiarity to children of this age range: ball–shoe, birdie–kitty, baby–doggy, and book–car. As in earlier studies[8,34], trials with target words that the parent reported their child did not understand were excluded from analysis on a child-by-child basis. Children in the FT group were reported to know significantly more of the test words (M = 7.9, SD = 0.5) than children in the PT group (M = 7.5, SD = 1.0), $t(92) = 2.3$, $p = 0.02$, although all children were reported to know at least five (of 8) target words.

Videorecordings of the LWL sessions were later prescreened and coded offline by trained research assistants unaware of the position of the target picture. Trials where the participant was inattentive or not looking at one of the target pictures at noun onset, or where there was parental interference, were excluded from further coding. At a 33-millisecond (ms) resolution, eye gaze was coded as fixed on one of the images (left or right), between the images, or not looking at either image. Depending on which picture the child was looking at target noun onset, trials were later designated as target- or distracter-initial.

Accuracy was computed as the mean proportion looking to the target picture between 300-1800 ms from target noun onset on all target- and distracter-initial trials combining trials from the two testing sessions. Reaction time (RT) was computed as the mean latency (in ms) to initiate a gaze shift from the distracter to target image on all distracter-initial trials during a period of 300 to 1800 ms after target noun onset. Because shifts initiated prior to 300 or after 1800 ms from target noun onset were less likely to be in response to the verbal stimulus, they were excluded from the computation of RT.

To establish reliability, 25% of the sessions were randomly selected and recoded. Inter-coder agreement was 98% for the proportion of frames within 300–1800 ms from noun onset identified as on the target vs. the distracter picture. Proportion of trials on which RT agreed within one frame was 95%.

Outcomes at Age 4½ Years

Children's receptive vocabulary abilities were assessed using the Peabody Picture Vocabulary Test, 4th Ed. (PPVT-4)[39]. On each trial, the child was asked to point to the picture corresponding to the examiner's prompt. Expressive language skills were assessed via the expressive language composite on the Clinical Evaluation of Language Fundamentals-Preschool-2 (CELF-P2)[40], comprised of the Word Structure, Expressive Vocabulary, and Recalling Sentences sub-tests. Children's non-verbal IQ was assessed using the Brief-IQ subscale of the

Leiter International Performance Scale-Revised (Leiter-R)[41]. Administration and responses are non-verbal, capturing skill in problem-solving and reasoning independent of a child's language abilities. For all assessments at 4½ years, standard scores were derived based on the child's chronological age at test.

Analysis Plan

We first present descriptive statistics for demographic, predictor, and outcome variables. To explore group differences as a function of birth group, we conduct independent sample t-tests. We next present a series of hierarchical multiple regressions to explore the contribution of language processing efficiency at 18 months to receptive vocabulary, expressive language, and non-verbal outcomes at 4½ years. All models first consider SES and age at test as control variables and then demonstrate the predictive contribution of two measures of language processing efficiency (Accuracy and RT) on each outcome measure beyond controls. Finally, we introduce the corresponding interaction terms to assess whether relations differed as a function of birth group. All tests were two-tailed and levels of significance were set at $p < 0.05$.

Results

Scores on behavioral measures

Table 2 presents scores on the behavioral assessments for both FT and PT infants at 18 months of age, adjusted for prematurity. Infants in both the FT, $t(48) = 11.4$, $p < .0001$, and PT, $t(44) = 7.9$, $p < .0001$, groups performed significantly above chance, on average. While children in the FT group were both more accurate and faster in the LWL task than children in the PT group, these differences did not achieve statistical significance. All children contributed at least 2 valid shifts to the computation of RT ($M = 18.4$, range = 2–32). However, the children born PT contributed significantly fewer trials ($M = 16.3$, $SD = 6.8$) than the children born FT ($M = 20.3$, *SD* = 6.3), *t*(90) = 2.95, *p* = 0.004. Table 2 also presents the results of the standardized assessments at 4 ½ years. Children born FT children performed significantly higher than children born PT on all standardized measures.

Predictions to language outcomes at pre-kindergarten

We now examine the extent to which measures of language processing efficiency assessed at 18 months (Accuracy and RT) account for significant variance in later outcomes at 4 ½ years and importantly, whether birth group moderates these relations. Table 3 shows the models predicting receptive vocabulary scores on the PPVT-4. Model 1a shows that group differences remained, even after controlling for the covariates of age at test and SES. Model 1b shows that knowing children's accuracy scores in the looking-while-listening task at 18 months adds more than 10% variance. Model 1c shows that adding the interaction term between group and accuracy does not significantly increase overall model fits, indicating that the relation between accuracy and receptive vocabulary was parallel in the two groups. Similarly, Model 1d shows that adding RT adds nearly 14% additional variance, and again, Model 1e shows that group does not moderate this relation. These effects are illustrated in Figure 1.

Table 4 shows the models predicting the expressive language skills using the CELF-P2. Model 2a again shows that birth group differences remain after controlling for covariates of age and SES. Model 2b shows that adding accuracy increases the overall variance accounted for by nearly 20%, accounting for over 30% of the variance taken together. The addition of the interaction term is not significant in Model 2c, indicating that the association between accuracy and later expressive language is not moderated by birth group. Model 2d adds RT from the LWL task as a main effect, adding approximately 17% additional variance. Again, birth group does not moderate this relation, as shown in Models 1e and illustrated in Figure 2.

Finally, Table 5 presents the models predicting to non-verbal IQ. Model 3a shows that group differences remained significant after controlling for age and SES. Models 3b and 3d show significant main effects of accuracy and RT, adding 7-9% additional variance. Model 3c shows a non-significant interaction term, indicating that the strength of the relation between early accuracy scores and non-verbal outcomes is similar in children born FT and PT. However, Model 3e shows that the interaction term is significant for RT, adding nearly 5% additional variance compared to the model with only the main effect. As illustrated in Figure 3, simple slopes analyses reveal that the relations between early RT and later non-verbal outcomes is significant in children born PT, $t(88) = 4.13$, $p < 0.001$, but not in those children born FT, $t(88) = 0.60$, $p = 0.55$. Moreover, follow-up analyses revealed that this interaction was observed, even when controlling for children's oral language skills, $F(2,87) = 4.88$, $p = .009$, suggesting that this effect was not an artifact of positive associations between non-verbal IQ and expressive language abilities.

Discussion

This longitudinal descriptive cohort study explored the long-term associations between early language processing efficiency at 18 months and receptive vocabulary, expressive language, and non-verbal cognitive outcomes, 3 years later, at 4 ½ years in children born FT and PT. The study yielded four main results. First, while birth group differences in early processing efficiency were not statistically significant in toddlerhood, children born PT scored below their FT peers, on average, on all outcomes assessed at pre-kindergarten. These differences persisted after controlling for age at test and SES. This pattern suggests that the impacts of preterm birth on neurodevelopment are not static, but appear to accumulate over development and become more evident as the skills under examination become more challenging[27].

Second, early language processing efficiency was a significant predictor of language skills, specifically, receptive vocabulary and expressive language, in children from both birth groups, consistent with several earlier findings using this procedure in only children born PT[15,34]. Thus, individual differences in those component skills that are evoked during real-time language comprehension early in language learning travel together with more knowledge-based assessments of expressive language use in children born FT and PT as children develop.

The main goal of this study was to explore whether the patterns of association would be similar in children born FT and PT. While relations to these outcomes have been explored independently in different samples of children, this study was the first to directly compare patterns of relations across birth groups. Thus, the third major finding was that for language measures, we saw parallel relations between variation in early language processing efficiency and variation in outcomes across birth group. This finding suggests that variation in early processing efficiency reflects children's early information processing skills that have implications for later language learning, including receptive vocabulary and expressive language. While the causal nature of these associations is not clear, these findings are consistent with the view that variation in early language processing efficiency reflects learning mechanisms that crucially relate to later outcomes in children born FT and children born PT, even though the children born PT as a group are at increased risk for language delays.

Fourth, we found group differences in the pattern of association between early language processing speed and non-verbal IQ three years later. Speed of language processing was more strongly related to later non-verbal IQ in children born PT than in children born FT. While previous studies reported relations between language processing efficiency and working memory in children born FT[15], in that study, working memory skills were assessed using verbal measures of working memory, rather than the non-verbal tasks used here. The LWL task taps not only language comprehension, but also attention, verbal and non-verbal working memory, and processing speed. Non-verbal IQ assesses non-verbal reasoning, along with attention, and visual-spatial working memory. The finding of associations in the PT and not FT group suggests greater continuity between processes underlying early language processing efficiency and processes involved in non-verbal IQ in the PT than in the FT group. These findings are consistent with studies at older ages in which non-verbal skills had stronger associations to later reading scores in PT than the FT samples[24]. Among children born PT, performance in a wide range of domains seems to be reflective of the neuropsychological and neurobiological integrity of their entire processing system whereas among children born FT, performance seems to be more tightly linked to domains that have a strong language basis. Future studies should examine whether these more general links found in the PT group are maintained across sub-populations of children born PT, specifically those with and without evidence of injury and dysmaturity of white matter tracts[42,43].

Limitations

Limitations to this study include the relatively small sample size. In addition, most children came from relatively high-SES backgrounds and do not represent the full range of SES in children born FT or PT. The outcomes were assessed at a single time point prior to when the children had entered school. It is not certain whether the gaps in performance in standardized tests would be reduced once children were receiving support from formal schooling, though other studies do not find a reduction of group differences with age[27,44]. Each domain of functioning at age 4 ½ years was assessed with a single measure. Different instruments or assessments in different domains of functioning may have yielded different results.

Conclusion.

Although children born PT had consistently lower scores on receptive language, expressive language, and non-verbal IQ, the patterns of predictive associations suggests that the underlying processing mechanisms and component skills are generally similar across these birth groups. The sole exception was that RT was a significant predictor of non-verbal IQ in the PT and not the FT group. This finding is consistent with previous results that suggest that decrements in performance in PT children may be more domain-general than those seen in children born FT. Clinical assessment of children around the time of school entry should take into account birth group status and assess a range of component skills. Further, variation in early language and other academic-related skills in early childhood may have its roots in somewhat different components skills in children from different sub-populations or clinical groups. Ongoing research should continue to explore other potential moderators of the relations between early language processing skills and later outcomes.

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Table 1. Descriptive statistics (M (SD)) and tests of group differences in demographic variables for full term-born (FT: n = 49) and preterm-born (PT: n = 45) children.

	FT	PT	χ^2 or t	p
Male (%)	51.0	50.0	0.04	1.0
Gestational Age (wks)	40.1 (1.1)	29.6 (1.9)	33.4	**0.001****
Birth Weight (g)	3550.7 (457.7)	1256.3 (277.3)	29.66	**0.001****
Maternal Education (yrs)	16.7 (1.4)	16.3 (1.9)	0.93	0.35
SES	59.7 (7.2)	56.6 (8.8)	1.88	0.06
Age: Time 1 (mos)	18.8 (0.6)	18.7 (0.6)	0.63	0.53
Age: Time 2 (mos)	55.5 (2.7)	54.4 (1.4)	2.56	**0.02***

Note: SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status [38].

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 2. Descriptive statistics (M (SD)) and tests of group differences on behavioral assessments in full term-born (FT: n = 49) and preterm-born (PT: n = 45) children at 18 months and 4 ½ years

	FT	**PT**	***t***	***p***
18 mos				
Acc	0.66 (.10)	0.63 (.11)	1.50	0.14
RT	724 (147)	771 (167)	1.44	0.15
4 ½ years				
Receptive Vocabulary	122.1 (16.6)	110.2 (18.7)	3.25	**0.002****
Expressive Language	116.4 (14.0)	107.6 (14.9)	2.99	**0.003****
Non-Verbal IQ	109.6 (15.8)	96.7 (20.2)	3.43	**0.001*****

Note: Acc: Proportion looking to target on the looking-while-listening task [6]; RT: Mean response time on the looking-while-listening task [6]; Receptive Vocabulary: Standard scores on the Peabody Picture Vocabulary Test – 4th Edition (PPVT-4) [39]; Expressive Language: Standard scores on the Clinical Evaluation of Language Fundamentals-Preschool, 2nd Edition (CELF-P2) [40]; Non-Verbal IQ: Brief-IQ from Leiter-R (Roid & Miller, 2011).

*p < 0.05, **p < 0.01, ***p < 0.001

Table 3. Multiple regression models (unstandardized coefficients (SE)) predicting receptive language (PPVT-4) at 4 ½ years in full term-born (FT: *n* = 49) and preterm-born (PT: *n* = 45) children from early language processing efficiency at 18 months (corrected for prematurity).

	Model 1a	Model 1b	Model 1c	Model 1d	Model 1e
Age at test	1.65 (0.83)	**1.88 (0.78)***	**1.90 (0.79)***	**1.83 (0.77)***	**1.83 (0.77)***
SES	0.43 (0.22)	0.31 (0.21)	0.32 (0.22)	0.35 (0.21)	0.38 (0.21)
Group	**-8.66 (3.77)***	-6.93 (3.56)	-0.47 (21.85)	**-6.62 (3.51)**	-19.39 (16.35)
Acc	**--**	**60.43 (16.57)*****	**65.6 (23.97)****	**--**	**--**
Acc x Group	--	**--**	-9.95 (33.18)	--	--
RT	--	--	--	**-.04 (0.01)****	**-0.05 (0.02)****
RT x Group	--	--	--	--	0.02 (0.023
R^2	**16.9*****	**27.8*****	**27.9*****	**30.3*****	**30.8*****
r^2-change	**--**	**10.9*****	0.1	**13.4*****	0.5

Note: r^2-change for Models 1b and 1d in reference to Model 1a; Models 1c and 1e in reference to Models 1b and 1d, respectively. SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status [38]; Acc: Proportion looking to target on the looking-while-listening task [6]; RT: Mean response time on the looking-while-listening task [6]

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 4. Multiple regression models (unstandardized coefficients (SE)) predicting expressive language (CELF-P2) at 4 ½ years in full term-born (FT: n = 49) and preterm-born (PT: n = 45) children from early language processing efficiency at 18 months (corrected for prematurity).

	Model 2a	Model 2b	Model 2c	Model 2d	Model 2e
Age	-0.24 (0.69)	0.02 (0.61)	-0.06 (0.61)	-0.08 (0.62)	-0.08 (0.62)
SES	**0.40 (0.18)***	0.27 (0.16)	0.25 (0.16)	0.33 (0.17)	0.33 (0.17)
Group	**-7.89 (3.08)***	**-5.87 (2.75)**	-28.22 (16.71)	**-6.07 (2.80)***	-5.97 (13.16)
Acc	--	**65.77 (12.82)*****	**47.33 (18.39)***	--	--
Acc x Group	--	--	34.46 (25.41)	--	--
RT	--	--	--	**-0.04 (0.01)*****	**-0.04 (0.01)****
RT x Group	--	--	--	--	-0.01 (0.02)
R^2	**13.8****	**33.5*****	**34.9*****	**31.0*****	**31.0*****
r^2-change	--	**19.7*****	1.4	**17.2*****	0.01

Note: r^2-change for Models 2b and 2d in reference to Model 2a; Models 2c and 2e in reference to Models 2b and 2d, respectively. SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status [38]; Acc: Proportion looking to target on the looking-while-listening task [6]; RT: Mean response time on the looking-while-listening task [6]

*p < 0.05, **p < 0.01, ***p < 0.001

Table 5. Multiple regression models (unstandardized coefficients (SE)) predicting non-verbal IQ (Leiter-R) at 4 ½ years in full term-born (FT: *n* = 49) and preterm-born (PT: *n* = 45) children from early language processing efficiency at 18 months (corrected for prematurity).

	Model 3a	Model 3b	Model 3c	Model 3d	Model 3e
Age at test	1.40 (0.87)	1.59 (0.84)	1.49 (0.84)	1.56 (0.82)	1.57 (0.80)
SES	0.31 (0.23)	0.22 (0.23)	0.19 (0.23)	0.24 (0.22)	0.15 (0.22)
Group	**-10.34 (3.89)****	**-8.83 (3.78)***	-35.36 (23.07)	**-8.62 (3.72)***	30.89 (16.95)
Acc	--	**49.85 (17.64)****	28.52 (25.39)	--	--
Acc x Group	--	--	40.89 (35.07)	--	--
RT	--	--	--	**-0.04 (0.01)****	-0.01 (0.02)
RT x Group	--	--	--	--	**-0.05 (0.02)***
R^2	**15.4****	**22.4*****	**23.5*****	**24.8*****	**29.4****
r^2-change	--	**7.0****	1.1	**9.4****	**4.5***

Note: r^2-change for Models 3b and 3d in reference to Model 3a; Models 3c and 3e in reference to Models 3b and 3d, respectively. SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status [38]; Acc: Proportion looking to target on the looking-while-listening task [6]; RT: Mean response time on the looking-while-listening task [6].

**p* < 0.05, ***p* < 0.01, ****p* < 0.001

Figure Captions

Figure 1. Modeled relations between language processing speed at 18 months and receptive vocabulary (PPVT-4) at 4 ½ years in children born full term (FT: *n* = 49) and preterm (PT: *n* = 45).

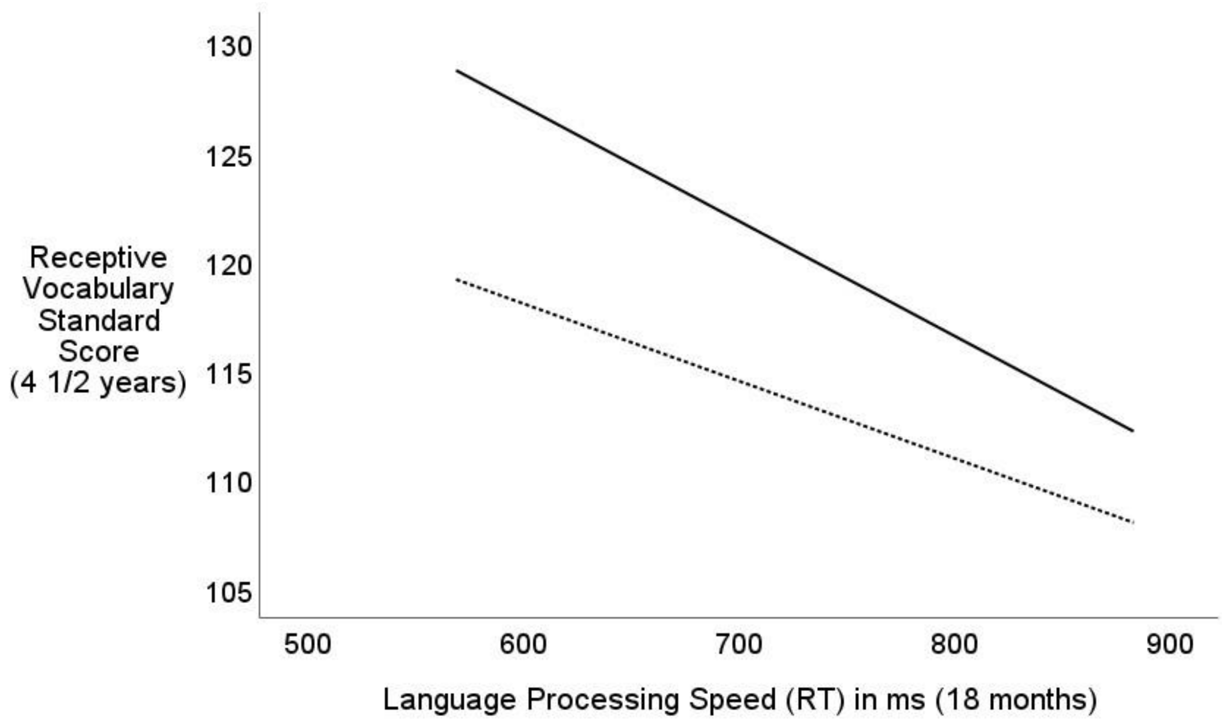

Figure 2. Modeled relations between language processing speed at 18 months and expressive language (CELF-4) at 4 ½ years in children born full term (FT: *n* = 49) and preterm (PT: *n* = 45).

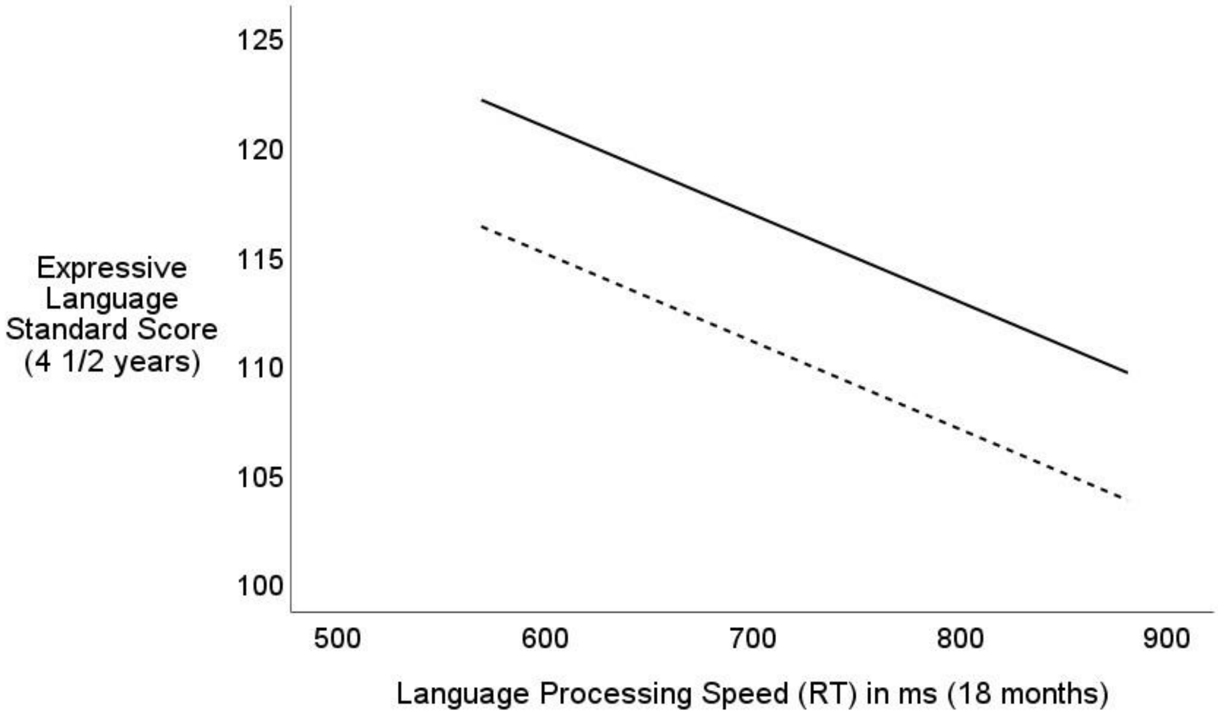

Figure 3. Modeled relations between language processing speed at 18 months and nonverbal IQ (Leiter-R) at 4 ½ years in children born full term (FT: *n* = 49) and preterm (PT: *n* = 45).