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

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Running Head: Language processing efficiency in children born preterm and full term

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The data that support the findings of this study are openly available at https://github.com/vmarchman/PTFTcomparison

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Research Highlights

- Associations between early language processing efficiency in toddlerhood and later standardized test performance inform the extent to which information processing skills support learning across domains.
- Comparing patterns of associations in children from different clinical groups (e.g., children born full term and preterm) further informs whether neurobiological risk alters developmental pathways.
- Early language processing efficiency was associated with language and pre-literacy outcomes to a similar extent for preterm and full term children, suggesting similar underlying mechanisms.
- Association between processing speed and non-verbal IQ differed by group; processing speed supports learning in a broader range of domains in preterm than term children.

Abstract

Associations between children's early language processing efficiency and later language, literacy, and non-verbal outcomes shed light on the extent to which early information processing skills support later learning across domains. 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 take across development. We compared patterns of associations between early language processing efficiency (accuracy and reaction time) in the looking-while-listening (LWL) task and school-relevant skills in children born full-term (FT) and preterm (PT). Participants (n=94, 49 FT, 45 PT) were assessed in the LWL task at 18 months (corrected for degree of prematurity in PT group) and on standardized tests of expressive language, pre-literacy (print knowledge and phonological awareness), and non-verbal IQ at 4 ½ years. Early language processing efficiency was associated with later language and pre-literacy outcomes (r^2 change ranged from 19.8 to 7.1, $p < 0.01$) to a similar extent in PT and FT children, controlling for age at test and SES, suggesting similar mechanisms of learning in these domains for PT and FT children. However, birth group moderated the association between reaction time 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 from caregivers. Over the last few decades, research has demonstrated that young children, like adults, process speech incrementally as it unfolds in time (Jones & Rowland, 2017; Zangl & Fernald, 2007) and efficiently extract aspects of the speech signal that can support language learning (Fernald et al., 1998, 2006; Law & Edwards, 2014). 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 (Fernald et al., 2008). 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 *accuracy*, defined as the proportion of time looking at the target and not the distracter, and speed or *reaction time* (RT), defined as the number of milliseconds (ms) to shift gaze from the distracter to the target picture in response to the verbal cue.

Research using the LWL paradigm has demonstrated substantial individual differences in real-time language comprehension that link to a variety of outcomes at older ages. 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 (Fernald et al., 2006; Fernald & Marchman, 2012; Law & Edwards, 2014; Peter et al., 2019). These results suggest that the LWL task captures variation in foundational skills that underlie early language learning including attention, working memory, and processing speed (Fernald & Marchman, 2012). One interpretation is that faster speed of processing allows 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 (Jones & Rowland, 2017; Peter et al., 2019). 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 (Chater & Christiansen, 2018; McCauley & Christiansen, 2019). Evidence that variation in early language experience may help shape the development of language processing efficiency further supports this view (Adams et al., 2018; Hurtado et al., 2008).

Studies have shown that variation in early performance in the LWL task is associated with children's skills beyond vocabulary. For example, individual differences in early language processing efficiency in toddlerhood has been linked to variation in morphosyntactic skill in preschool-aged children (Jones & Rowland, 2017; Lew-Williams & Fernald, 2007; Peter et al., 2019). Early processing efficiency has also been shown to be associated with later verbal intelligence quotient and verbal working memory scores in school-aged children (Marchman & Fernald, 2008). Associations between early processing efficiency and a range of cognitive outcomes suggests continuity between skills involved in early real-time language processing and skills that skills that are involved in learning a range of later complex 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 (Fernald & Marchman, 2012), a skill that forms the foundation for learning in a variety of domains.

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 (Venker et al., 2013; Venker & Kover, 2015). Premature birth, which affects approximately 10.2% of all births in the US (March of Dimes, 2020), is associated with increased risk of adverse neurodevelopmental outcomes, especially for those infants born very (birth at $<$ 32 weeks gestation) or extremely (birth at $<$ 28 weeks gestation) preterm (PT) (Adams-Chapman et al., 2018). Children born PT are at increased risk for language-related deficits, including poor literacy outcomes, compared to their full-term (FT) peers (Borchers et al., 2019; Guarini et al., 2010; Sansavini et al., 2011). Moreover, PT birth is associated with injury to white matter tracts in the brain and characteristics of white matter pathways is associated with clinical language outcomes in toddlerhood (Dubner et al., 2020) as well as in prekindergarten (Zuk et al., 2021).

Recent studies using the LWL task suggest that age-related changes in language processing efficiency are comparable in children born FT and PT (Loi et al., 2017). Moreover, associations between early processing efficiency in the LWL task and vocabulary growth are similar in children born PT and FT (Marchman et al., 2019). In addition, long-term associations to both language and non-verbal outcomes in children born PT were analogous to those observed in prior studies with children born FT (Marchman et al., 2016, 2018). However, to our knowledge, no studies to date have directly compared the relations between early language processing efficiency in the LWL task and later outcomes at pre-kindergarten in 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 are weaker or masked by other factors 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, given the evidence that associations are generally stronger in younger children and children with smaller vocabularies than older children with larger vocabularies (Peter et al., 2019). 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 suggest that a common set of underlying mechanisms are at play in supporting learning in children born FT and PT. 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.

Children born PT are particularly susceptible to delays in the development of reading skills (Guarini et al., 2010). In older children, the construct of processing speed has also been implicated as a component of language and reading deficits in school-aged children and adolescents born PT (Lee et al., 2011). Previous studies assessing relations between early performance in the LWL paradigm and later outcomes have focused on language outcomes, but not on specific skills that form the foundation for later literacy. Early literacy skills are supported by children's ability to recognize and name letters and numbers (i.e., print knowledge) and to manipulate sounds and syllables (i.e., phonological awareness). While these early literacy skills are generally highly correlated with oral language abilities (Dickinson et al., 2010), little is known about continuities between these skills and those involved in spoken language processing. One possibility is that early spoken language processing may strongly correlate with skills that are directly related to spoken language and weakly correlate with skills that are implicated in written language skills. At the same time, skills like phonological awareness rely heavily on attention and working memory, component skills that are also strongly implicated in real-time language comprehension (Gorman, 2012; Gresch et al., 2018; Peter et al., 2019). No studies have yet explored literacy-based outcomes in relation to early spoken language processing in either children born FT or PT.

The 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, suggesting similar underlying mechanisms. 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 children born FT and PT, but non-verbal skills and executive function abilities were linked to reading outcomes only in children born PT (Borchers et al., 2019). These results were interpreted to suggest that children born PT may recruit a broader set of skills when learning to read, compared to their FT counterparts. More research is warranted that explores associations between early language processing efficiency and a broad array of both verbal and non-verbal skills in these populations (Rose & Feldman, 1995; Sansavini et al., 2011).

In this study, we document early language processing efficiency at 18 months and language, pre-literacy, and non-verbal skills at 4 ½ years in children born FT and PT. Our main interest is to explore patterns of relations between measures of language processing efficiency (accuracy and RT) and a range of component verbal and non-verbal skills. We asked:

- Do children born PT show delays in expressive language, pre-literacy skills (print knowledge, phonological awareness), 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 expressive language, pre-literacy, and non-verbal outcomes at pre-kindergarten in PT and FT children?
- Does birth group moderate the strength of these relations? And, if so, are the moderations consistent across the domains of oral expressive language, pre-literacy, and non-verbal IQ?

Method

Participants

Participants were 49 children (24 females) born full term (FT) and 45 children (23 females) born preterm (PT). Children were participating in a longitudinal study, and some of the data in the current analyses have been previously reported for a subset of these children (Adams et al., 2018; Loi et al., 2017; Marchman et al., 2016, 2018). Recruitment 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. Exclusionary criteria 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 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 (Blumenshine et al., 2010). Most mothers in both groups were college-educated. SES was also estimated using a modified version of the Hollingshead Four Factor Index (HI) (Hollingshead, 1975), 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.

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 and 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) procedure (Fernald et al., 2008). In this task, 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. A video camera placed between the pictures provided a video-record of the child's looking responses that was later coded frame-by-frame. Children were tested in two visits approximately one week apart. Each session lasted approximately 5 minutes. Caregivers' vision was blinded so that they could not inadvertently bias their child's responses.

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 matched for animacy and salience, with order and picture position counterbalanced across participants. Auditory stimuli were simple well-formed sentences that presented the 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. Because the LWL task is intended to capture individual differences in the speed with which children process words that are familiar to them (Fernald et al., 2008), the stimulus words were selected based on familiarity to children of this age range: ball–shoe, birdie–kitty, baby–doggy, and book–car. Performance on unfamiliar words is likely to be at chance or result in more variable looking times. Therefore, as in earlier studies, in order to assess efficiency of language processing specifically for words that were known to all children (e.g., Fernald et al., 2006; Fernald & Marchman, 2012), 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 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. Trials on which the child was not looking at one of the pictures at target noun onset were excluded from analysis.

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

Expressive Language. Expressive language skills were assessed via the expressive language composite on the Clinical Evaluation of Language Fundamentals-Preschool-2 (CELF-P2) (Semel et al., 2004) comprised of the Word Structure, Expressive Vocabulary, and Recalling Sentences sub-tests.

Pre-literacy. Pre-literacy skills were assessed using the print knowledge and phonological awareness subscales of the Test of Early Preschool Literacy (TOPEL) (Lonigan et al., 2007). Print awareness examines children's abilities to recognize and name letters and numbers. Phonological awareness assesses word elision and blending abilities.

Non-verbal IQ. Children's non-verbal IQ was assessed using the Brief-IQ subscale of the Leiter International Performance Scale-Revised (Leiter-R) (Roid & Miller, 2011). 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, following standard practice not to adjust for degree of prematurity in children older than 2 years of age.

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 language, pre-literacy, 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

Description of the sample

Table 2 presents scores on the behavioral assessments for both FT and PT infants at 18 months of age, adjusted for prematurity. Note that while the FT children were more efficient in the LWL task as infants, these differences did not achieve statistical significance. We can note that 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 ($M = 16.3$, $SD = 6.9$) than the children born FT ($M = 20.3$, $SD = 6.3$), $t(92) = 3.0$, $p = 0.004$. At 4 ½ years, children born FT children performed significantly higher than children born PT on all measures.

Predictions to language and literacy outcomes at pre-kindergarten

We now present a series of multiple regression models that 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 the expressive language skills using the CELF-P2. Model 1a shows that birth group differences remain after controlling for covariates of age and SES. Model 1b shows that adding Accuracy from the LWL task at 18 months increases the overall variance accounted for by nearly 20%, accounting for over 30% of the variance taken together. Critically, the addition of the interaction term is not significant in Model 1c, indicating that the association between Accuracy scores and later expressive language is not moderated by birth group. Model 1d 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 1.

Tables 4 and 5 present a similar pattern for pre-literacy outcomes at pre-kindergarten. For print knowledge, Model 2a shows that group differences remain after accounting for the covariates of age and SES. Models 2b and 2d show that early language processing efficiency as measured by both Accuracy and RT in the LWL task predict significant variance beyond the covariates and group. Models 2c and 2e demonstrate that the interaction terms are not significant. A similar pattern is shown in Table 5 for phonological awareness. Models 3b and 3d show that accuracy and RT account for more than 13% and 19% of additional variance, respectively, beyond age, SES, and group. Critically, Models 3c and 3e show that the interaction terms are again not significant. Thus, for both pre-literacy measures, early language processing efficiency predicted significant variance in outcomes and the strength of those relations were similar for children born FT and PT. These effects are illustrated in Figures 2 and 3.

Finally, Table 6 presents the models predicting to non-verbal IQ. Model 4a shows that group differences in IQ remained significant after controlling for age and SES. Models 4b and 4d show significant main effects of accuracy and RT in the LWL task, adding 7-9% additional variance to the prediction of non-verbal IQ at pre-kindergarten. Model 4c 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 4e 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 4, a simple slopes analyses reveals that the relations between early RT and later non-verbal outcomes is significant in children born PT, $t(88) = 4.13$, $p < 0.0001$, 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, $F(6, 87) = -0.05$, $p = 0.02$, suggesting that this effect was not an artifact of relations 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 oral expressive language, pre-literacy, and non-verbal cognitive outcomes at 4 ½ years in children born FT and PT. The study yielded five 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. Second, early language processing efficiency was a consistent predictor of oral expressive language, consistent with several earlier findings using the LWL procedure (e.g., Marchman et al., 2018; Marchman & Fernald, 2008). Third, this study is the first to demonstrate continuities between early language processing efficiency and pre-literacy skills, explored here in terms of print knowledge and phonological awareness. Taken together, these results suggest that variation in early language processing efficiency is linked with a host of later skills that form the foundation for school-readiness and academic achievement.

A major goal of this study was to explore whether the patterns of association would be similar in children born FT and PT. While relations to at least some of 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 fourth major finding was that for most of the 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 learning across a variety of domains, including language and literacy. While the causal nature of these associations is not clear, these findings suggest that the mechanisms involved in learning are similar in children born FT and children born PT who may be at increased risk for language delays.

At the same time, the study also 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 (Marchman & Fernald, 2008), 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 (Borchers et al., 2019). 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 may 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 with and without dysmaturity of white matter tracts (Bruckert et al., 2019; Feldman et al., 2012).

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 (Kovachy et al., 2015). 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 expressive language, pre-literacy skills, 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 suggests 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. Descriptives (M (SD)) and tests of group differences in demographic variables for FT (n = 49) and 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)	29.1	**0.001****
Maternal Education (yrs)	16.7 (1.4)	16.3 (1.9)	0.9	0.35
SES	59.7 (7.2)	56.6 (8.8)	1.9	0.06
Age: Time 1 (mos)	18.8 (0.6)	18.7 (0.6)	0.6	0.53
Age: Time 2 (mos)	55.5 (2.7)	54.4 (1.4)	2.5	**0.02***

Note: SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975).

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

Table 2. Descriptives (M (SD)) and tests of group differences on behavioral assessments in FT (n = 49) and PT (n = 45) children at 18 months and 4 ½ years

	FT	**PT**	***t***	***p***
18 mos				
Acc	0.66 (.10)	0.63 (.11)	1.53	0.13
RT	724 (147)	772 (167)	1.45	0.15
4 ½ years				
Expressive Language	116.5 (14.0)	107.6 (14.9)	3.01	**0.003****
Print Knowledge	112.0 (13.1)	105.2 (15.4)	2.30	**0.024***
Phonological Awareness	113.0 (13.6)	101.4 (19.0)	3.46	**0.001*****
IQ	109.6 (15.8)	96.7 (20.2)	3.46	**0.001*****

Note: Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008); Expressive Language: Standard scores on the Clinical Evaluation of Language Fundamentals-Preschool, 2nd Edition (CELF-P2) (Semel et al., 2004); Print Knowledge/Phonological Awareness: Standard scores on the Test of Preschool Early Literacy (TOPEL) (Lonigan et al., 2007); 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 expressive language (CELF-P2) at 4 ½ years in FT (*n* = 49) and PT (*n* = 45) children from early language processing efficiency at 18 months (corrected for prematurity). 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,

	Model 1a	Model 1b	Model 1c	Model 1d	Model 1e
Age	-0.24 (0.69)	0.02 (0.61)	-0.06 (0.61)	-0.08 (0.62)	-0.08 (0.62)
SES	**0.41 (0.18)***	0.27 (0.17)	0.25 (0.17)	0.33 (0.17)	0.33 (0.17)
Group	**-7.89 (3.1)***	-5.87 (2.8)	-28.22 (16.7)	**-6.07 (2.8)***	-5.97 (13.2)
Acc	--	**66.28 (12.9)*****	**48.08 (18.6)***	--	--
Acc x Group	--	--	34.46 (25.5)	--	--
RT	--	--	--	**-0.04 (0.01)*****	**-0.04 (0.01)****
RT x Group	--	--	--	--	-0.01 (0.02)
R^2	**13.8***	**33.6*****	**35.0*****	**31.0*****	**31.0*****
r^2-change	--	**19.8*****	1.4	**17.1*****	0.01

respectively. SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975); Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008)

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 4. Multiple regression models (unstandardized coefficients (SE)) predicting print knowledge (TOPEL) at 4 ½ years in FT (n = 49) and 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	-0.58 (0.68)	-0.36 (0.63)	-0.41 (0.64)	-0.47 (0.66)	-0.47 (0.66)
SES	0.25 (0.18)	0.14 (0.17)	0.13 (0.17)	0.20 (0.18)	0.23 (0.18)
Group	**-0.65 (3.07)***	-4.87 (2.87)	-16.92 (19.54)	-5.35 (2.98)	-18.3 (13.96)
Acc	**--**	**54.67 (13.42)**	**44.86 (19.54)***	**--**	**--**
Acc x Group	**--**	**--**	18.56 (26.82)	**--**	**--**
RT	**--**	**--**	**--**	**-0.03 (0.01)****	**-0.04 (0.01)****
RT x Group	**--**	**--**	**--**	**--**	0.02 (0.02)
R^2	8.2	**22.7*****	**23.1*****	**16.1****	**16.8****
r^2-change	**--**	**14.4*****	0.4	**7.8****	0.8

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. Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008).

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

Table 5. Multiple regression models (unstandardized coefficients (SE)) predicting phonological awareness (TOPEL) at 4 ½ years in FT (*n* = 49) and PT (*n* = 45) children from early vocabulary and language processing skills at 18 months (corrected for prematurity).

	Model 3a	Model 3b	Model 3c	Model 3d	Model 3e
Age	-0.24 (0.78)	0.01 (0.71)	-0.08 (0.72)	-0.04 (0.68)	-0.03 (0.68)
SES	**0.53 (0.21)***	0.**40 (0.19)***	0.38 (0.19)	**0.43 (0.18)***	**0.39 (0.19)***
Group	**-10.27 (3.48)****	**-8.34 (3.23)***	-32.97 (19.7)	**-8.03 (3.09)***	9.99 (14.38)
Acc	**--**	**63.4 (15.3)*****	43.33 (21.89)	**--**	**--**
Acc x Group	**--**	**--**	37.96 (30.03)	**--**	**--**
RT	**--**	**--**	**--**	**-0.05 (0.01)*****	**-0.04 (0.02)****
RT x Group	**--**	**--**	**--**	**--**	-0.02 (0.02)
R^2	**17.6****	**31.2*****	**32.4*****	**37.1*****	**38.3*****
r^2-change	--	**13.6*****	1.2	**19.5*****	1.2

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. Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008).

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

Table 6. Multiple regression models (unstandardized coefficients (SE)) predicting non-verbal IQ (Leiter) at 4 ½ years in FT (*n* = 49) and PT (*n* = 45) children from early language processing efficiency at 18 mos (corrected for prematurity).

	Model 4a	Model 4b	Model 4c	Model 4d	Model 4e
Age at test	1.41 (0.87)	1.60 (0.84)	1.5 (0.84)	1.56 (0.82)	1.57 (0.80)
SES	0.31 (0.23)	0.21 (0.23)	0.18 (0.23)	0.24 (0.22)	0.15 (0.22)
Group	**-10.34 (3.9)****	**-8.8 (3.8)***	-34.6 (23.2)	-8.62	30.89 (16.95)
Acc	--	**50.5 (17.7)****	29.5 (25.6)	--	--
Acc x Group	--	--	39.78 (35.2)	--	--
RT	--	--	--	**-0.04 (0.01)*****	-0.01 (0.02)
RT x Group	--	--	--	--	**-0.05 (0.02)***
R^2	**15.4****	**22.5*****	**23.6*****	**24.8*****	**29.4****
r^2-change	--	**7.1****	0.01	**9.4****	**4.5***

Note: r^2-change for Models 4b and 4d in reference to Model 4a; Models 4c and 4e in reference to Models 4b and 4d, respectively. SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975); Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008).

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

Figure 1. Predicted relations between language processing speed at 18 months and expressive language (CELF-4) at 4 ½ years in children born FT (*n* = 49) and PT (*n* = 45).

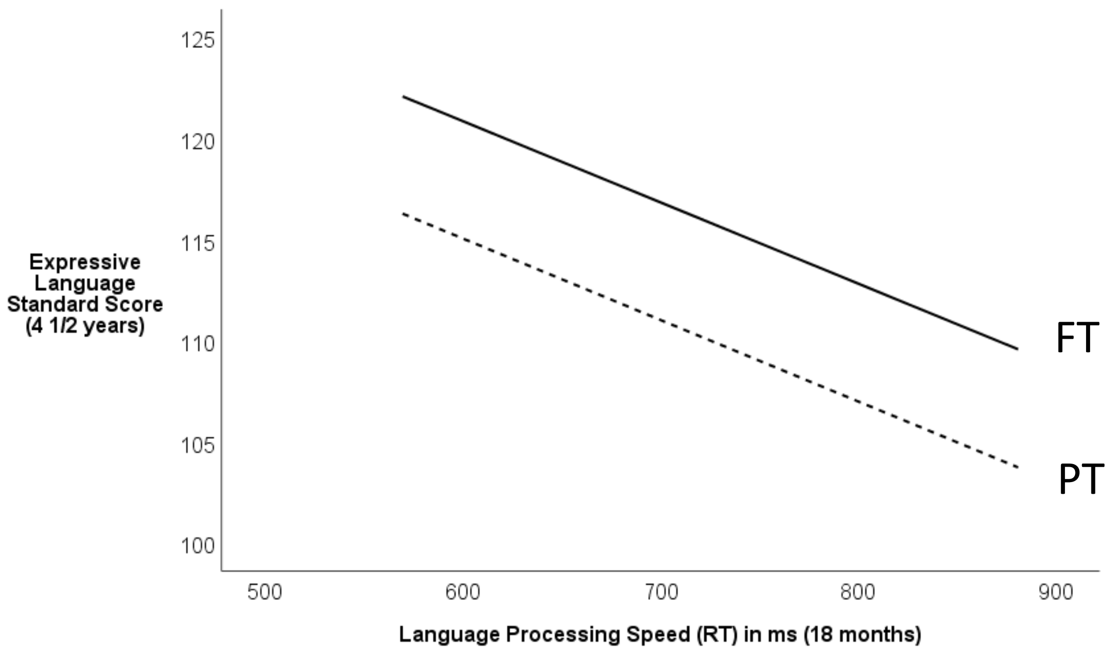

Figure 2. Predicted relations between language processing speed at 18 months and print knowledge (TOPEL) at 4 ½ years in children born FT (n = 49) and PT (n = 45).

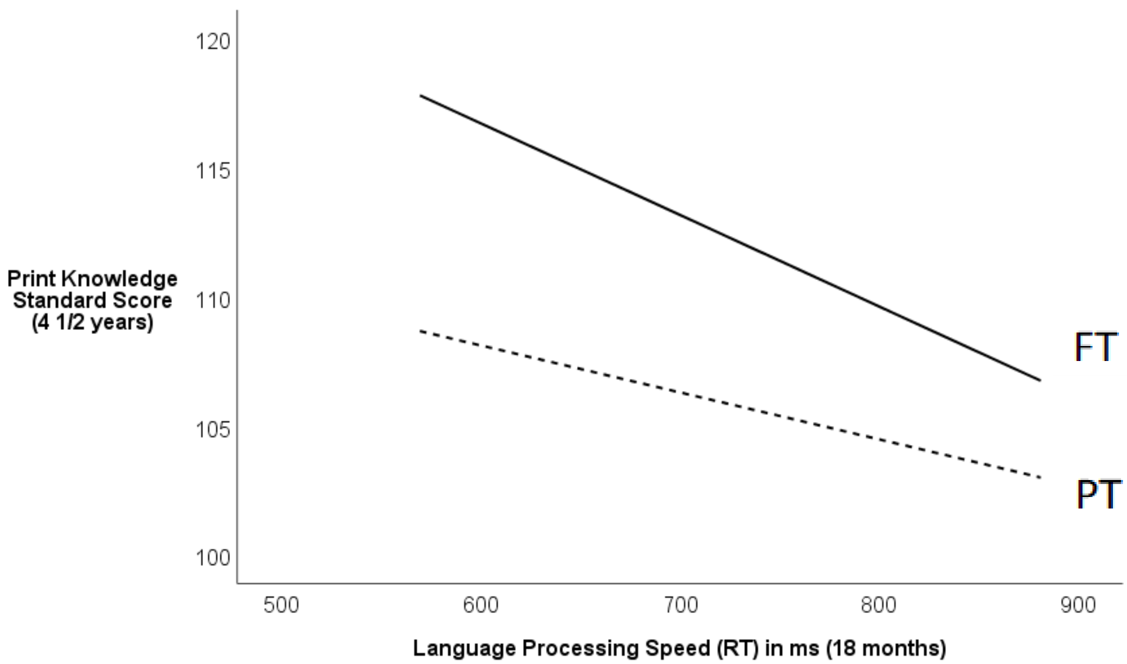

Figure 3. Predicted relations between language processing speed at 18 months and phonological awareness (TOPEL) at 4 ½ years in children born FT (n = 49) and PT (n = 45).

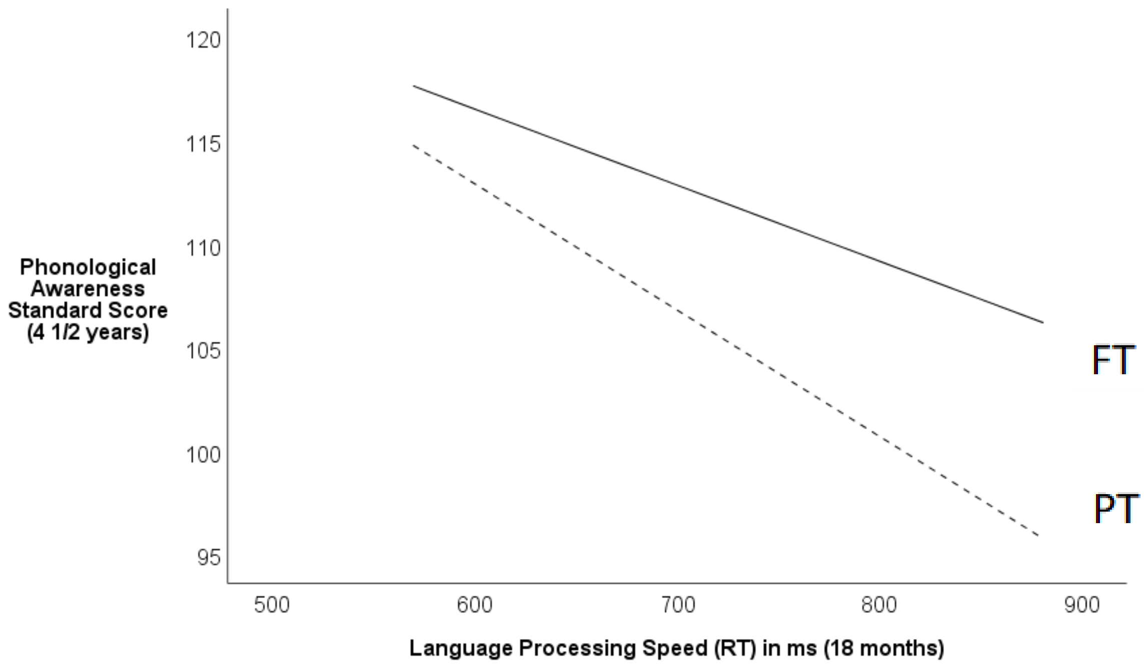

Figure 4. Predicted relations between language processing speed at 18 months and nonverbal IQ (Leiter-R) at 4 ½ years in children born FT (n = 49) and PT (n = 45).